C55.602:N21s/2

NSSL Special Report

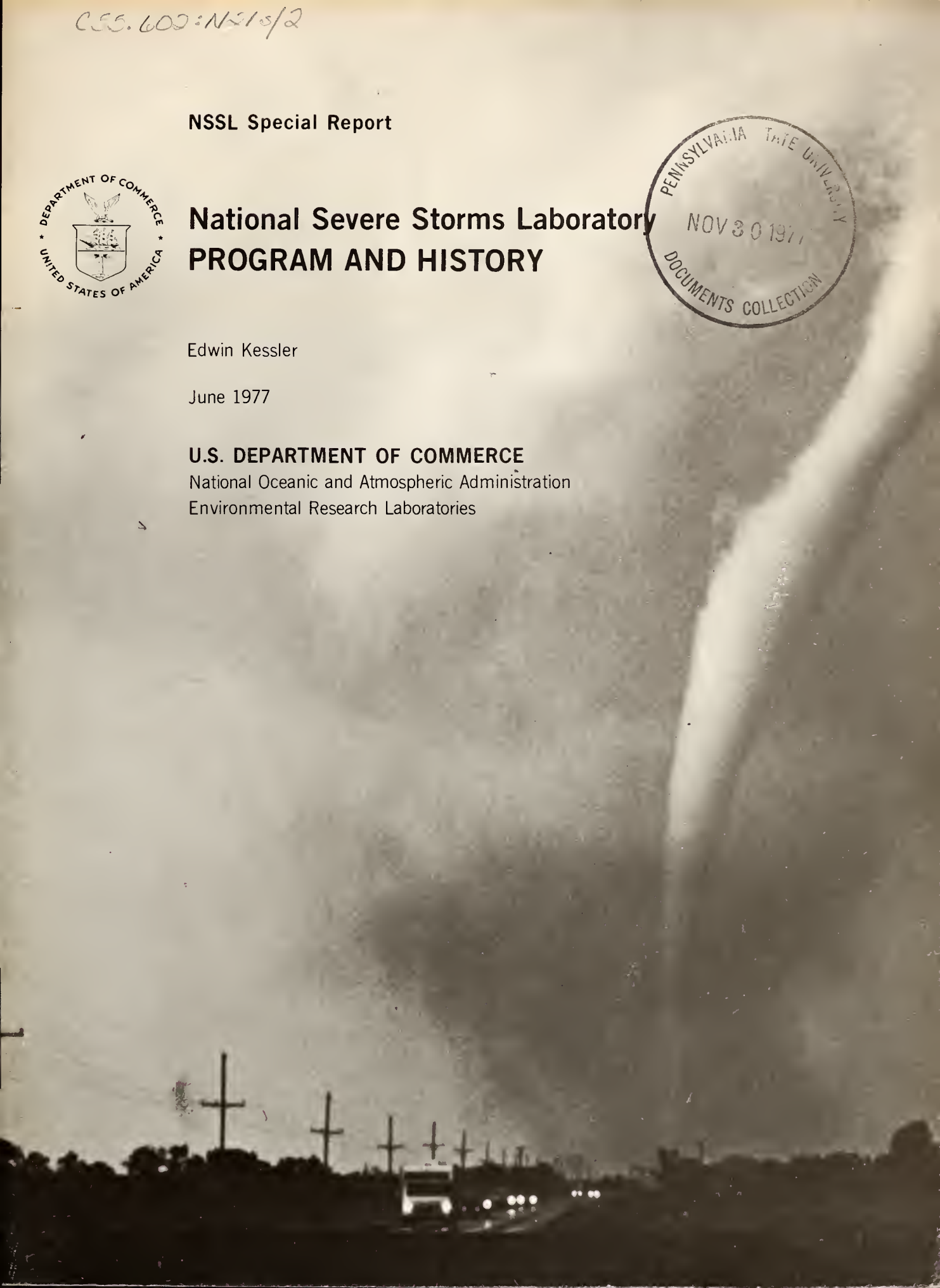
PENNSYLVANIA STATE UNIVERSITY
NOV 30 1977
DOCUMENTS COLLECTION

National Severe Storms Laboratory PROGRAM AND HISTORY

Edwin Kessler

June 1977

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories



NSSL Special Report

National Severe Storms Laboratory
PROGRAM AND HISTORY

Edwin Kessler

National Severe Storms Laboratory
Norman,Oklahoma

June 1977

U. S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator

Environmental Research Laboratories
Wilmot Hess, Director

Boulder, Colorado

U. S. Depository Copy

FOREWORD

The author of this Special Report has directed the National Severe Storms Laboratory (NSSL) since its formal inception at Norman, Oklahoma, in 1964. He has presented here details about the workings of a government laboratory that are often accessible to the public only with great difficulty. This report discusses what a typical government laboratory is involved with, where its funds come from, and where they go. Meant for both scientists and laymen, the report summarizes the history and the programs of the laboratory through September 1976. Objectives, organization, biographical sketches of staff, facilities, resources, key successes, current research, and outlook for the future are all included.

The current program exploits the pioneering work done at NSSL in multiple-Doppler radar observation of wind fields in severe thunderstorms. The program uses innovations in Doppler radar engineering to fill meteorological observing requirements and synthesizes Doppler wind field measurements with measurements from special aircraft, satellites, and conventional in-situ networks to obtain a coherent model of the severe thunderstorm. The Laboratory's work has led to significant improvement in techniques for forecast and warning of severe storms by operational weather services.

NSSL has enlisted and received participative support from many federal and state agencies, the military, and universities in carrying out its research and technology development programs. We expect that the Laboratory will continue to nurture and expand its multidisciplinary, multi-agency approach to severe storm research that has proved so successful.

W. N. Hess
Director, ERL

CONTENTS

		Page
1.	Introduction	1
2.	Objectives of the NSSL	5
3.	Organization, Staff, Funding	6
4.	Housing, Facilities	9
5.	Contracts, Grants	14
6.	Principal Accomplishments	16
7.	Current Program	20
7.1	Multiple Doppler Observations of Wind Fields	20
7.2	Pre-Cloud and Cloud Research at NSSL	20
7.3	Studies of the Moist Boundary Layer with a Turbulence Closure Model	22
7.4	Precursor Conditions for Storm Development	22
7.5	Thunderstorm Structure, Evolution, and Environment Interaction	24
7.6	Investigation of Tornadic Storms with Doppler Radar	24
7.7	Tornado Dynamics Research at NSSL	25
7.8	Storm Hazards to Aviation	25
7.9	Display of Radar Data at Sites Remote from the Console	27
7.10	Severe Storm and Tornado Identification with Doppler Radar	27
8.	The Future	29
9.	Acknowledgments	30
Appendix A.	Biographies of NSSL Professional Staff—1976	30
Appendix B.	History of Engineering Development of NSSL	59
Appendix C.	Publications and Reports by NSSL Staff FY–76	64

Frontispiece. This building has housed the National Severe Storms Laboratory since it was completed in 1972. It is located in University of Oklahoma's Swearingen Research Park, and the terminal building of Norman's Municipal Airport is only half a mile away. The NSSL building is leased to NOAA by the University.

National Severe Storms Laboratory PROGRAM AND HISTORY*

Edwin Kessler

1. Introduction

Man's interest in weather dates from prehistory and extends around the world, because weather influences are important almost everywhere. Even in technologically advanced societies, somewhat shielded from direct and immediate exposure to the elements, food supply and patterns of culture relate closely to local seasonal characteristics and progression. Today's global reach of commerce and industry has established need for complex facilities and equipment to examine our atmosphere from pole to pole.

In the scientific revolution, first a European phenomenon primarily, early attention was directed to weather systems of one to several days duration and involving distances of a thousand kilometers or so, that dominate temperate latitude weather. Coincidentally, observation and prediction of these systems on the scale of a day or so have carried more utility for man's activity than do our efforts to utilize information from larger and smaller weather systems. Even in 1976, we have only scant capability for skillful foreshadowing of the very large scale systems associated with season-long anomalies, and we have been defied in many observational and predictive aspects of small scale but physically extreme thunderstorms which produce great property damage and casualties (see Table 1.1). A purpose of the National Severe Storms Laboratory is to improve observation and prediction of thunderstorms, particularly those which damage persons and property.

During World War II, considerable meteorological capability was developed in the U. S. Armed Services. Shortly after that war ended, some of this capability was engaged to study thunderstorms, very important, but only poorly observed and understood. The Thunderstorm Project utilized closely spaced stations for measurements at the Earth's surface; stations with balloon-borne equipment measured conditions in the free atmosphere; radars observed precipitation distribution and development; and instrumented aircraft probed thunderstorms directly. The Thunderstorm Project utilized closely spaced stations for measurements at the Earth's surface; stations with balloon-borne equipment measured conditions in the free atmosphere; radars observed precipitation distribution and development; and in-storm drafts up to 25,000 ft. The 1949 report of the Thunderstorm Project, with the many questions it ponders, constitutes a prescription to which recent work can be traced.

Table 1.1 Storm Deaths and Damage in the United States

Type of Storm	Approximate Average Annual Deaths (1970-76)	Approximate Average Annual Property Damage (1970-76)
Tornado	125	$300 million
Lightning	110	200 million*
Hail	<5	750 million**
Storm Floods	100	100 million

* Includes livestock
**Includes damage to crops, about $680 million at 1973 price levels or about 1.6% of farmers' cash receipts received that year for all crops. (See the U. S. Census, and Borland, writing in the Preprints of the 1975 Symposium on Hail held at the National Center for Atmospheric Research).

*This report documents work of the Laboratory through September 30, 1976.

As aviation was the primary aegis for weather service developments during World War II, that industry was again a center of meteorological concerns in the late 1950's. It was thought that the higher operating altitudes of modern aircraft, especially jet powered aircraft, would carry them comfortably over the tops of severe thunderstorms, but many incidents and some tragic accidents demonstrated differently. In fact, the phenomenal increase of air traffic, and aerodynamic properties of swept wing jet aircraft, became associated with increased sensitivity of commercial aviation to severe weather. In addition, severe weather has had progressively increased impacts on agriculture, construction, and recreation industries, and public attention was drawn in the fifties to tragic tornadoes at Flint, Michigan; Worcester, Massachusetts; and Waco and San Angelo, Texas. The U. S. Weather Bureau, responding to these concerns, established a Severe Local Storms Forecasting Unit, first at Washington, D. C., and thereafter at Kansas City, Missouri, to upgrade the quality of forecasts of extreme conditions including tornadoes. Concurrently the Weather Bureau inaugurated a national network of 10-cm radars (WSR–57's) for storm warning.

The National Severe Storms Project (NSSP) subsequently was established at Kansas City. Through use of instrumented aircraft and other observational facilities, and through fundamental investigations of processes associated with severe storms, the NSSP sought to identify criteria for safe and economical flight near thunderstorms, and sought to improve procedures for storm detection, identification, prediction, and warning.

The NSSP did benefit from proximity to operational forecasters, but large densities of both people and aircraft in the Kansas City area inhibit use of that place as headquarters for field investigations involving flight into severe storm centers by instrumented aircraft and a farflung network of well-exposed stations for surface weather observations. Such observations were not being well enough orchestrated anywhere in the United States and theoretical developments are increasingly irrelevant when the data base is weak. Therefore the NSSP established a field site, headquarters for an important observational program similar to the 1940's Thunderstorm Project, at the former North Base, U.S. Naval Air Station, Norman, Oklahoma. In 1964, the NSSP Headquarters was moved to Norman, and staff previously assigned at the field station were augmented by transfers from Kansas City. Also the newly appointed Director, Edwin Kessler, succeeded Director Clayton F. Van Thullenar, who retired, and Chief Scientist Chester W. Newton, who left NSSP for a post as senior scientist, National Center for Atmospheric Research, Boulder, Colorado. At that time the Weather Bureau's National Severe Storms Laboratory, National Hurricane Research Laboratory, and Research Flight Facility all reported to Robert H. Simpson in the Office of Meteorological Research.

While Oklahoma, Kansas, and Missouri all provide many severe local storms, the Norman geography better suits field investigations of storms. A special positive element at Norman is the University of Oklahoma where departments of Meteorology and Electrical Engineering provide important supplementary attraction to academically inclined staff demanded by a research facility. While physically separating research (Norman) and operations (Kansas City) has some troublesome aspects, these fade in light of the long time frame indicated for meaningful address to fundamental problems within severe storm mechanics. Recent experiences underscore lessons previously taught—continuous growth of knowledge and understanding is needed to meet ever-emerging new requirements of technologically oriented society.

A stable research program should pursue understanding to promote constructive new technology with beneficial applications. It was well recognized when NSSL was established in Norman, that observations must be tied to high quality research at the Laboratory. NSSL's location in central U. S., with its many storms of interest, fosters a relevance in research that would be difficult to assure elsewhere. And observations tied to high quality science inspire confidence in other users of the data. Administrative arrangements should promote interaction between the many operating components whose work could touch severe storm problems and the many elements of the research community whose goals, methods, or results would relate to those of severe storm investigators.

With establishment of the Environmental Science Services Administration (ESSA) in 1965, NSSL was grouped with other units oriented toward fundamental research, in a new office, the ESSA Research Laboratories, directed consecutively by Jerome Spar and George Benton. In 1970, NSSL became a component of NOAA's Environmental Research Laboratories, headquartered now in Boulder, Colorado, and directed by Wilmot N. Hess (Fig. 1.1). NSSL maintains close relationships today with its counterpart in NOAA's National Weather Service, the National Severe Storms Forecast Center in Kansas City, Missouri, directed by Allen D. Pearson.

The mission of the Environmental Research Laboratories (ERL) is to conduct an integrated program of fundamental research, related technology development, and services to improve understanding and prediction of the geophysical environment comprising the oceans and inland waters, the lower and upper atmosphere, the space environment, and the Earth. The following participate in the ERL missions:

MESA

Marine EcoSystems Analysis Program. Plans, directs and coordinates the regional projects of NOAA and other federal agencies to assess the effect of ocean dumping, municipal and industrial waste discharge, deep ocean mining, and similar activities on marine ecosystems

OCSEA

Outer Continental Shelf Environmental Assessment Program Office. Plans and directs research studies supporting the assessment of the primary environmental impact of energy development along the outer continental shelf of Alaska; coordinates related research activities of federal, state, and private institutions

WM

Weather Modification Program Office. Plans, directs, and coordinates research within ERL relating to precipitation enhancement and mitigation of severe storms. Its National Hurricane and Experimental Meteorology Laboratory (NHEML) studies hurricane and tropical cumulus systems to experiment with methods for their beneficial modification and to develop techniques for better forecasting of tropical weather. The Research Facilities Center (RFC) maintains and operates aircraft and aircraft instrumentation for research programs of ERL and other government agencies

AOML

Atlantic Oceanographic and Meteorological Laboratories. Studies the physical, chemical, and geological characteristics and processes of the ocean waters, the sea floor, and the atmosphere above the ocean

PMEL

Pacific Marine Environmental Laboratory. Monitors and predicts the physical and biological effects of man's activities on Pacific Coast estuarine, coastal, deep-ocean, and near-shore marine environments

GLERL

Great Lakes Environmental Research Laboratory. Studies hydrology, waves, currents, lake levels, biological and chemical processes, and lake-air interaction in the Great Lakes and their watersheds; forecasts lake ice conditions

GFDL

Geophysical Fluid Dynamics Laboratory. Studies the dynamics of geophysical fluid systems (the atmosphere, the hydrosphere and the cryosphere) through theoretical analysis and numerical simulation using powerful, high-speed digital computers

APCL

Atmospheric Physics and Chemistry Laboratory. Studies cloud and precipitation physics, chemical and particulate composition of the atmosphere, atmospheric electricity, and atmospheric heat transfer, with focus on developing methods of beneficial weather modification

NSSL

National Severe Storms Laboratory. Studies severe-storm circulation and dynamics, and develops techniques to detect and predict tornadoes, thunderstorms, and squall lines

WPL

Wave Propagation Laboratory. Studies the propagation of sound waves and electromagnetic waves at millimeter, infrared, and optical frequencies to develop new methods for remote measuring of the geophysical environment

ARL

Air Resources Laboratories. Studies the diffusion, transport, and dissipation of atmospheric pollutants, develops methods of predicting and controlling atmospheric pollution, monitors the global physical environment to detect climatic change

AL

Aeronomy Laboratory. Studies the physical and chemical processes of the stratosphere, ionosphere, and exosphere of the Earth and other planets, and their effect on high-altitude meteorological phenomena

SEL

Space Environment Laboratory. Studies solar-terrestrial physics (interplanetary, magnetospheric, and ionospheric); develops techniques for forecasting solar disturbances; provides real-time monitoring and forecasting of the space environment

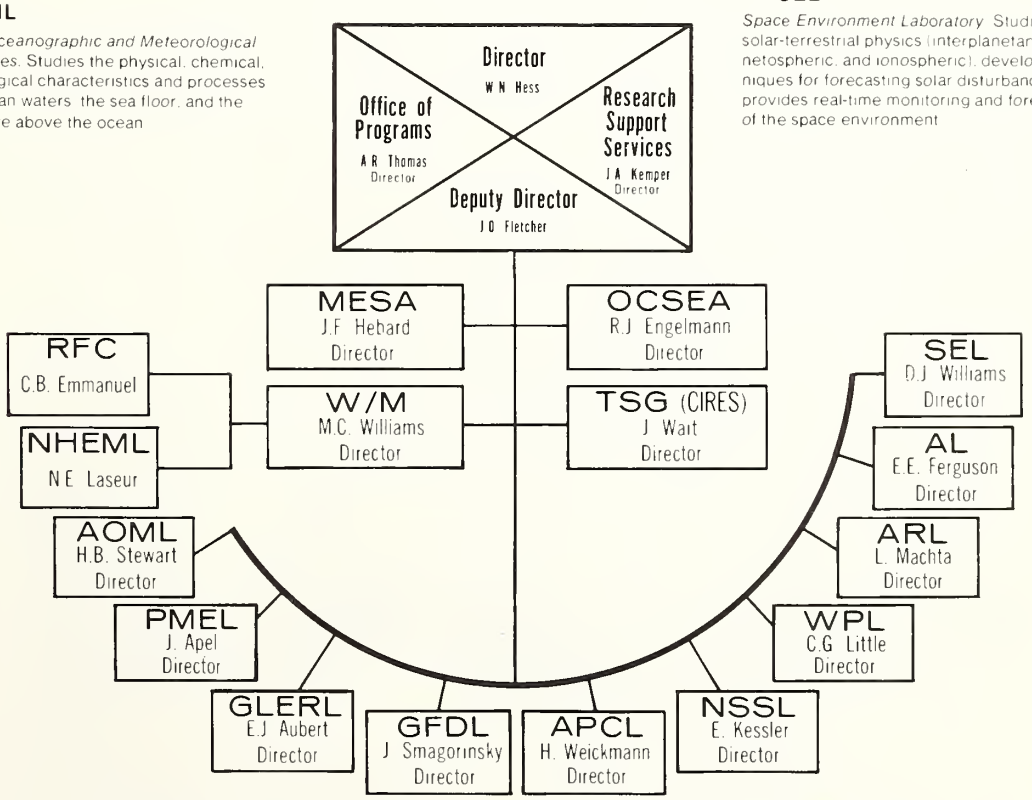


Figure 1.1 Mission and organization of the Environmental Research Laboratories.

Figure 2.1 Some of nature's most awesome phenomena are studied at the National Severe Storms Laboratory.

2. Objectives of the NSSL

The National Severe Storms Laboratory (NSSL) seeks to understand processes that create and sustain thunderstorms and their manifestations—hail, heavy rain, lightning, and tornadoes (Fig. 2.1)—and to develop improved techniques for storm observation and prediction. What conditions are necessary or sufficient to initiate storms and why do storms decay? What forces determine storm motion, and what conditions promote tornadoes, excessive lightning, and hail in some storms and not nearby in others? How can we apply modern technology effectively to determination of thunderstorm processes, even in their highly variable and violent hearts? How shall we array our knowledge to illuminate processes consistent with those same physical laws that underlie late 20th century technology?

How shall NSSL meteorologists apply newfound knowledge to produce improved forecasts of storm formation? How shall potentially damaging storm features be observed more accurately, earlier in their development, and information about them communicated to persons who need it, in time to be of help to them?

What shall we do to apply newly developed knowledge in agriculture, construction, and land use, to promote practices which benefit society and contribute to a healthy and sustainable social organism?

Such broad questions are easy to ask, but they have little practical value for program guidance until questions are recast in light of particular hypotheses. Indeed, growth of knowledge is nowhere more clearly indicated than by increasing specificity in our questions: a) What makes a tornado? b) How does background rotation relate to tornado formation? c) How does thunderstorm outflow interact with the low level southerly jet on a storm's leading edge to enhance local convergence and spin-up? The NSSL technical program of 1976 is examined in detail in Section 7.

Beyond functions of data acquisition and research analysis, NSSL assists research on severe storms conducted throughout our country and abroad. Part of this assistance is provided through sharing NSSL data and through joint use of NSSL facilities. For example, instrumented aircraft frequently are brought to the NSSL area by other government agencies and by universities to cooperate in NSSL-coordinated programs involving both direct and remote probing. Another important aspect of NSSL's interactions with the meteorological community is its funding of grants to university investigators. NSSL maintains a modest grant program to support worthy storm investigations and to promote continuing and healthy liaison with university meteorology departments. Senior staff at NSSL are also encouraged to have some direct involvement in academic activities.

3. Organization, Staff, Funding

NSSL's staffing and funding history is indicated in Figs. 3.1 and 3.2. For our internal organization when we moved to Norman, see NSSL Report No. 23. For our present organizational structure and staff, see Fig. 3.3 and Table 3.1. On July 1, 1975, at the start of the 1976 fiscal year, NSSL had 42 full time permanent (FTP) employees* and 23 in categories other than FTP. On June 30, 1976, NSSL had 43 and 23, respectively, in these categories. On September 30, 1976, the end of the FY–76 "transition quarter",** the numbers were 44 and 22.

The Administrative group under Jack Andrews handles most of the administrative laboratory work that is outside the area of technical exchange among scientists. The Computing and Data Processing Unit, led by Kathryn Gray, also NSSL's Assistant Director, manages NSSL's major computing facilities, provides computer programming assistance to users elsewhere in the Laboratory, undertakes computer program development for major systems, and oversees dissemination of data to user groups throughout the country.

The Operations group directed by Kenneth Wilk installs and manages all of NSSL's facilities for storm observation which do not involve a substantial development effort at the edge of the art. Also the Operations group is NSSL's main point of contact with other operating agencies, such as the Federal Aviation Administration (FAA), and the National Weather Service (NWS), for which both the Operations Group and NSSL as a whole undertake considerable applied research.

Advanced Techniques, under Richard Doviak, develops atmospheric sensors at the edge of the art, operates equipment with techniques that are now nonstandard or changing rapidly, and investigates measurement of hydrometeors and atmospheric

*This includes several employed full time for a defined term. Term employees in Table 3.1 are marked with an asterisk along with those employed part time, temporarily, or on an intermittent work schedule.

**Fiscal Year 1976 was extended by a 3-month "transition quarter". Hereafter, fiscal years of 12-month duration start Oct. 1.

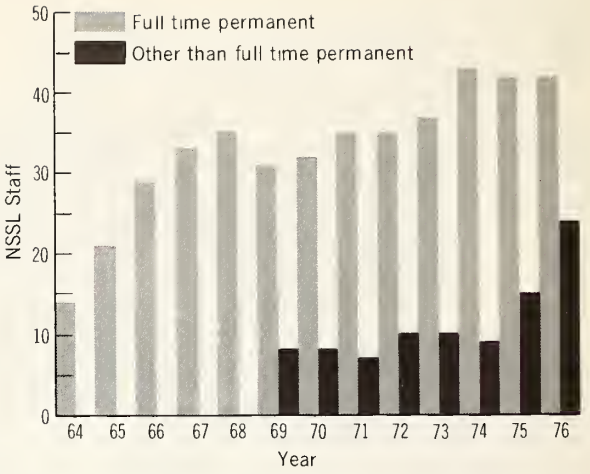


Figure 3.1 NSSL Staffing History. Prior to 1969, a small number of student assistants in NSSL were employed under terms of a contract with the Oklahoma University Research Institute. Present cooperation with the OU Meteorology Department includes a grant for support of students working on programs of mutual interest to the Department and to NSSL.

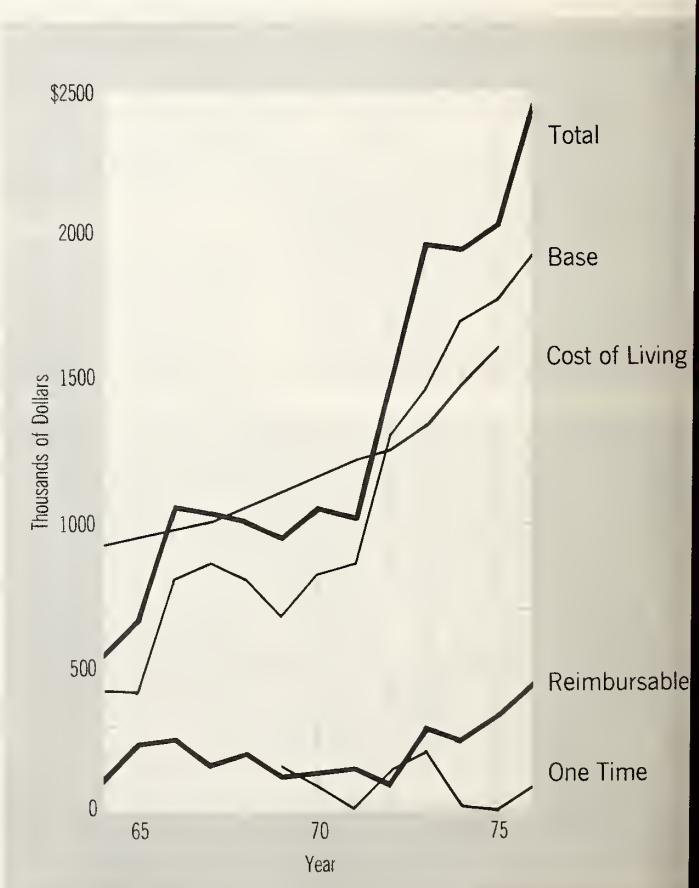


Figure 3.2 NSSL Funding History. "Base" comes to NSSL from Congress via Headquarters of NOAA and the Environmental Research Laboratories. "Reimbursable" funds are provided by other agencies for projects of special interest to them. "One Time" represents a special allocation from the ERL Director's Reserve for projects deemed worthy and for which other adequate funding is unavailable.

Table 3.1 NSSL Staff Assignments: July 1, 1975-September 30, 1976

DIRECTOR
Dr. Kessler
Ms. Cunningham—Secretary

ADVISORY COMMITTEE CHAIRPERSONS:
Archive—Mrs. Gray
Conservation—Mr. Shinn
Data Acquisition—Mr. Bumgarner
Data Utilization—Dr. Ray
Doppler Development—Mr. Sirmans
Equal Employment Opportunity—Mr. Andrews
Goals—Dr. Davies-Jones
Library—Mr. Brown
Manpower Utilization—Mrs. Gray
Observing Program—Mr. Brown
Space Utilization—Mr. Dooley

ADVANCED TECHNIQUES: Dr. Doviak
+− Ms. Gadberry—Secretary
Mr. Anderson
Mr. Carter
* Mr. Heck
* Mr. Hennington
* Mr. J. Moore (COOP student)
+ Dr. Pierce
+− * Mr. Reutlinger
Mr. Schmidt
Mr. Shinn
Mr. Sirmans
+− * Dr. Zrnic
+ * Mr. Zahrai

OPERATIONS: Mr. Wilk
Ms. Horwitz—Secretary
* Mr. Carpenter
Mr. Dooley
+− * Mr. Erickson
* Mr. Fredrickson
Mr. Jennings
Mr. Johnson
Mr. Lappie
* Mr. Loggains
− * Mr. McLaughlin
+ * Mr. Reece
Mr. Showell
+ * Mr. Tonemah
Mr. Wardius
Mr. Zittel

* Other than full time permanent
\+ Entered on duty during year
− Departed during year

ADMINISTRATION: Mr. Andrews
Ms. Graves—Admin. Asst.
* Ms. Ardrey—Editor
Mr. Clark—Photo
Ms. Farris—Photo
+ * Ms. Hartley—Library
* Ms. Killian
Mr. Sparger
− * Mr. Sykes
− * Ms. Turner

COMPUTING & DATA PROCESSING: Mrs. Gray
* Ms. Walton—Secretary
Mr. Bumgarner
Mr. Fortner
* Ms. May
Mr. Helm
* Mr. R. Moore (COOP student)
Mr. Weible

METEOROLOGY RESEARCH: Dr. Alberty
Ms. Hall—Secretary
* Mr. Berger
+ * Mr. Bothwell
Mr. Brandes
Mr. Brown
Mr. Burgess
* Dr. Burk (NRC Fellow)
Dr. Davies-Jones
− * Mr. Doswell
− Dr. Golden
Mr. Goff
+ * Dr. Hane
* Mr. Jobson
Mr. Lee
− Mr. Lemon
Mr. Nelson
* Mr. Purcell
Dr. Ray
* Mr. Safford
− Dr. Schaefer
+ Ms. Stokes
+− Dr. Wagner
* Mr. Watts
+ * Mr. Weaver
+ * Ms. Young
+ Mr. Zeigler
+ * Mr. Zipser

CONSULTANTS
Dr. Walker, University of Oklahoma
Dr. Stephens, Florida State University

state parameters. Doppler radar has had recent emphasis. But NSSL's Storm Electricity project under Senior Scientist Edward T. Pierce, newly arrived at NSSL, is now resuming an effort that has been dormant since Gilbert D. Kinzer retired in 1972. The storm electricity project will measure electrical parameters in Oklahoma storms and will coordinate field programs involving lightning investigators throughout the United States.

The Meteorolgical Research group, managed by Ronnie Alberty, merges observational, experimental, and theoretical data in search for knowledge of fundamental processes that create and sustain storms, and for improved forecasts and warnings.

It should be noted that individuals on NSSL staff customarily carry several assignments, some across the boundaries of the group to which they are nominally assigned. This facilitates communication within the Laboratory and maximizes use of talents that might otherwise tend to be neglected.

The funds necessary to carry out NSSL's projects, and their distribution, are indicated in Fig. 3.4 and Table 3.2. It should be noted that while most NSSL funding is provided directly through NOAA, there are important sources in other agencies, including the Federal Aviation Administration, Energy Research and Development Administration, National Aeronautics and Space Administration, and Nuclear Regulartory Commission. These funds support activities at NSSL of immediate importance to the agency concerned.

Biographies of NSSL professional staff are given in Appendix A.

Table 3.2 NSSL FY–76 Budget in Thousands

NAME	OBJECT CLASS ➡	LABOR	TRAVEL	TRANSPORTATION	RENT, COMM, UTILITIES	PRINTING	SERVICES	SUPPLIES	EQUIPMENT	GRANTS	TOTAL
LIBRARY	8C370400	3.8	—	—	—	7.7	3.0	3.6	0	—	$ 18.1
GRANTS	8C370401	—	—	—	—	—	—	—	—	62.8	62.8
ADVANCED TECHNIQUES	8C370403	292.4	4.0	—	3.0	—	—	—	10.0	—	309.4
OPERATIONS	8C370404	269.1	5.0	—	—	—	—	—	19.0	—	293.1
COMPUTER & DATA PROC.	8C370407	164.1	2.0	—	41.0	—	71.7	5.0	50.0	—	333.8
METEOROLOGY RESEARCH	8C370408	447.9	5.0	—	—	—	5.0	8.0	5.0	—	470.9
RESEARCH SUPPORT	8C370410	—	—	—	199.5	—	65.0	20.0	2.7	—	287.2
											$1775.3
SUPPORT	90004037	132.5	10.0	8.0	—	3.0	23.0	14.5	35.0	—	226.0
											$ 226.0
F.A.A. (Wilk)	RC360101	73.8	3.0	—	—	.5	19.3	1.0	52.1	—	$ 149.7
F.A.A. (Lee)	RC360205	22.3	1.3	—	—	.2	45.5	15.7	—	—	85.0
N.R.C. (Alberty)	RC370503	52.4	2.0	1.0	—	1.0	20.1	8.0	.5	20.0	105.0
NASA (Lee)	RC370603	1.6	.2	—	—	—	—	2.7	—	—	4.5
NASA (Lee)	RC370903	.6	.5	—	—	—	—	2.1	—	—	3.2
ERDA (Alberty)	RD840520	45.0	4.0	—	—	—	20.0	24.5	.5	6.0	100.0
											$ 447.4
											TOTAL FUNDING: $2448.7

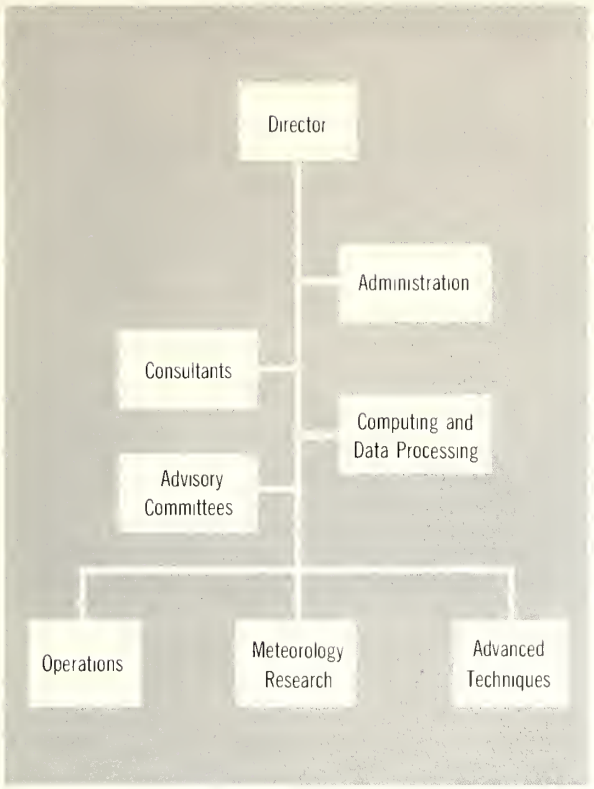


Figure 3.3 Administrative structure in the National Severe Storms Laboratory.

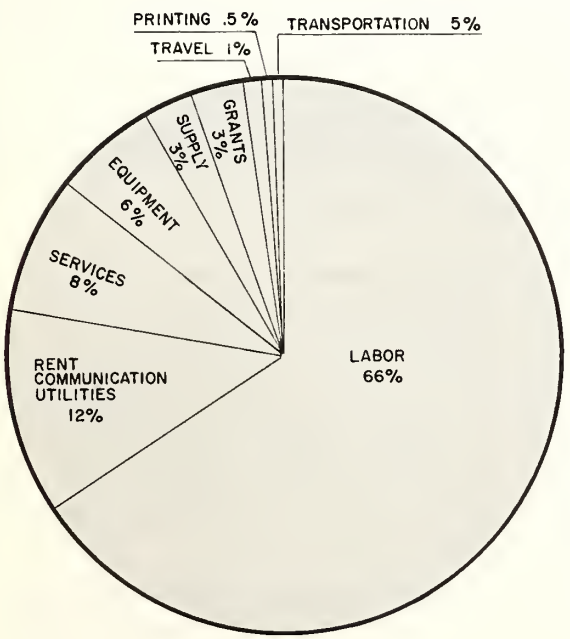


Figure 3.4 Distribution of FY–76 Base Funding by object class.

4. Housing, Facilities

NSSL was housed originally in a two-story wooden structure with an H-shaped floor plan, formerly a barracks. Working spaces were ample then and easily modified, but the building could not support a modern digital computer needed for data processing, analysis, and theoretical studies. Also the building represented a serious, pervasive fire hazard, and anxieties were only partially relieved with installation of heat and smoke sensors, and an alarm system that automatically alerted the fire department.*

In August 1972, NSSL occupied a new two-story building of reinforced concrete and glass, leased from the University of Oklahoma; the structure contains about 20,000 ft² on approximately one and one-half acres of land (see frontispiece).

Other space rented from the University of Oklahoma includes

a) A warehouse with 3,840 ft² of usable space;
b) Ground space of 718 ft² about 500 ft NE of NSSL headquarters for a rawinsonde (upper air sounding) facility;
c) Ground space of 17,820 ft² adjacent to the new quarters, with the Doppler radar laboratory building owned by NSSL and a tower containing a rangefinder;
d) Ground space of 17,820 ft² north and across the street from the NSSL with
    1) a small modulator building,
    2) A WSR–57 radar atop a 65 ft tower,
    3) a second tower with UHF and VHF radio antennas, and
    4) a third tower with IFF equipment (MPX–7 radar) to interrogate transponders aboard aircraft to determine aircraft position;
e) Ground space of one-half acre, south and adjacent to the Laboratory which contains a "benchmark" weather station. (This facility represents cooperation among NSSL, the University of Oklahoma, and the City of Norman, Oklahoma.)

*On April 3, 1967, fire near NSSL completely destroyed a similar barracks housing Oklahoma University's Meteorology Department, and on October 24, 1976, a former mess hall used for office space by various agencies was similarly destroyed.

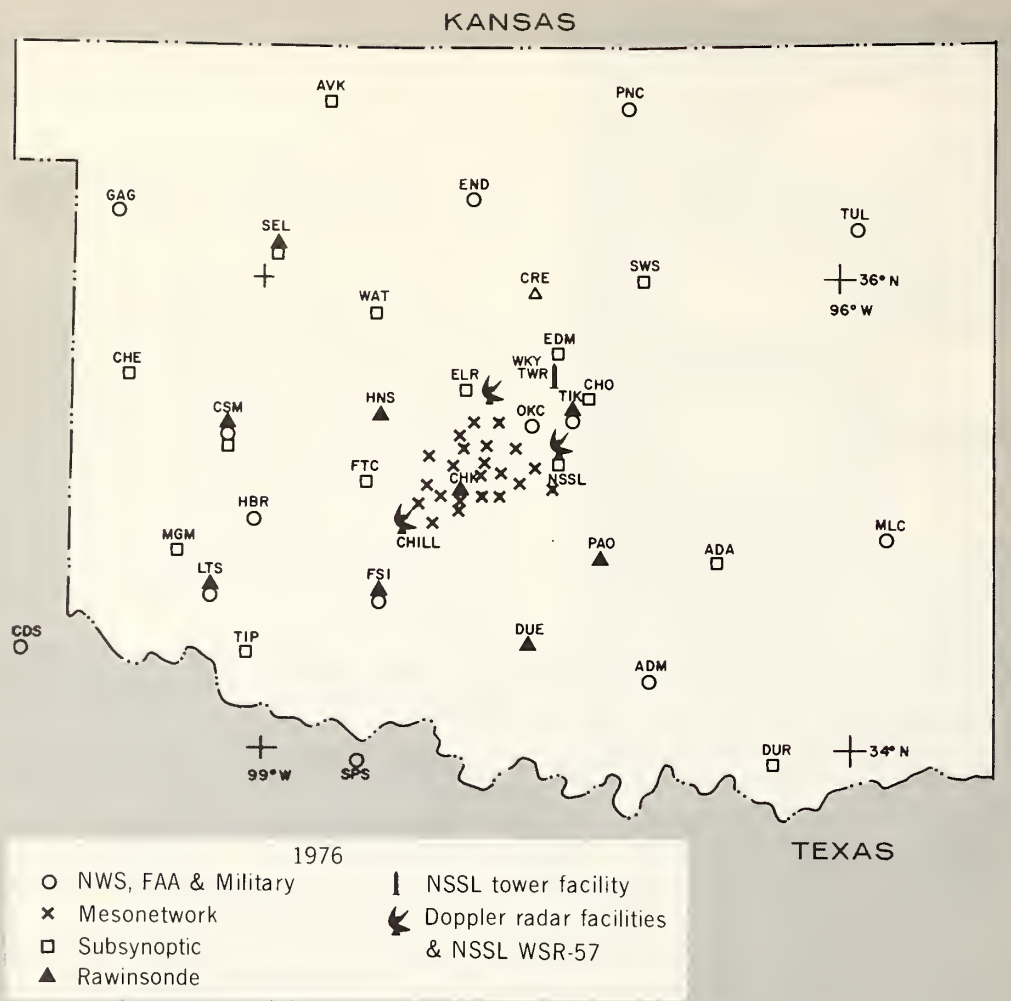


Figure 4.1 Surface facilities for weather observations operated by NSSL and other agencies.

f) One acre of land, leased from Will Rogers Airport Trust at Cimarron, Oklahoma, about 45 km NW of NSSL Headquarters, with NSSL's second Doppler radar and laboratory space for radar operators and electronic technicians.

NSSL's facilities for meteorology observations are specialized for acquisition of detailed information on thunderstorms.

Approximately 20 stations for surface observations (Fig. 4.1), distributed evenly across the state and in NW Texas, supplement data provided by observing stations of the National Weather Service and Department of Defense. These NSSL stations are installed, maintained, and calibrated by NSSL Operations staff, but are overseen daily by cooperators at airports and universities. All stations provide data records on strip charts, and a few can be interrogated by dataphone.

A second set of 25 stations is established for surface observations at spacings as close as 8 km in order to show details for synthesis with Doppler radar data. The station configuration may be varied from year to year in response to research requirements. A typical NSSL station for surface observations is shown in Fig. 4.2.

In addition to rawinsonde stations at NSSL, Ft. Sill, and Will Rogers International Airport, up to ten more radiosonde stations (Fig. 4.3) have been operated during special observational periods by personnel of the 6th Weather Squadron (Mobile), headquartered at Tinker Air Force Base. Accurate, detailed data in storms and storm environment are

Figure 4.2 Station operated by NSSL for continuous recording of wind, temperature, humidity, pressure, and rainfall.

Figure 4.3 Rawinsonde facility operated in cooperation with NSSL by the 6th Weather Squadron, Mobile, Tinker AFB, Oklahoma.

Figure 4.4 KTVY Television tower, fitted by NSSL with meteorological instruments to a height of 444 meters, and used in studies of thunderstorm gust fronts and structure of wind and temperature in the air layer next to the ground.

obtained at these stations with schedules and procedures designed at NSSL.

During January 1965, WKY–TV completed a 1500 ft (458 m) tall transmitter tower and subsequently agreed to allow NSSL its use for meteorological sensing. Today, the newly named KTVY tower is instrumented at six levels from 26 to 444 m to measure temperature and three-dimensional wind; pressure is measured at the first and sixth levels and the wet-bulb temperature at three levels (Fig. 4.4). All data from the tower and two nearby surface sites are recorded on both strip charts and magnetic tape, and can be displayed and recorded at NSSL Headquarters via telephone line.

NSSL operates three major radar systems. The WSR–57, similar to those in network operation by the National Weather Service, is equipped for precision calibration and digital tape recordings of reflectivity. A variety of automatic scanning sequences can be programmed.

NSSL's twin 10-cm Doppler radars (Fig. 4.5) focus NSSL's major effort in storm observing today. Separated by a 42 km NW–SE baseline, the Doppler observations can be combined to portray three-dimensional wind throughout the precipitation-containing volume of a suitably located storm. Each radar utilizes a high power (1-MW) coherent transmitter, with a 9.2-m (30-ft) diameter antenna, and much edge-of-the-art processing and recording

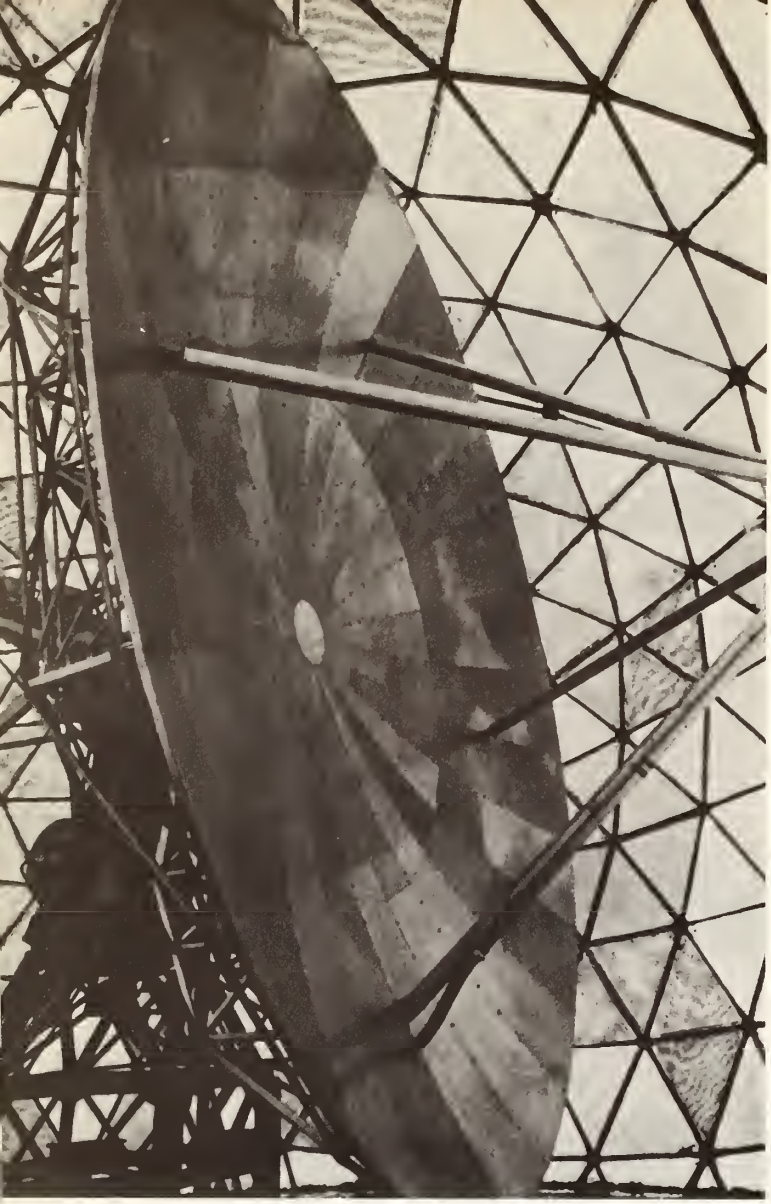


Figure 4.5 The Doppler antenna at Norman. The 9.2-m antennas of NSSL's Doppler radars radiate a beam only 0.8° wide at 10-cm wavelength.

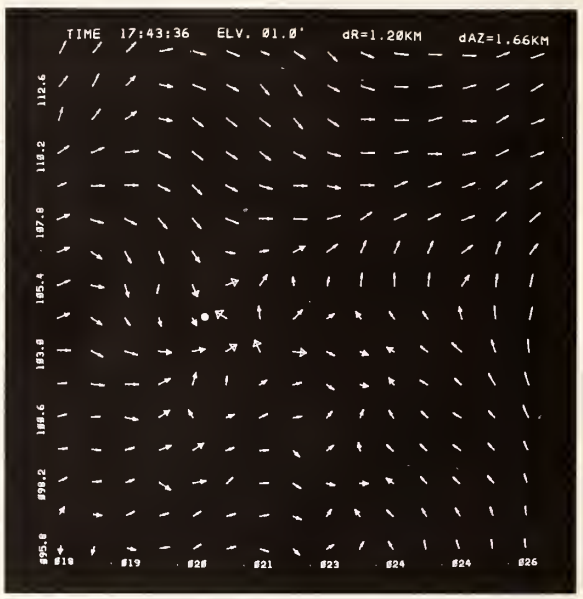


Figure 4.6 Multimoment Doppler radar data display for storm at Stillwater, Oklahoma, during intense tornado (white dot at 021° azimuth and 104 km range). Rotation of arrow from eastward pointing direction represents radial velocity (clockwise, toward; counterclockwise, away). Length of arrow shaft represents reflectivity; width of arrow head represents speed variability.

Figure 4.7 Specially instrumented F–4 aircraft used for measuring conditions inside thunderstorms.

Figure 4.8 LuCreta Butcher operates NSSL's Systems Engineering Laboratories 8600 computer. Equipment in the background includes an IBM 1401 for processing magnetic tapes, and a Calmagraphic X–Y reader/plotter system.

equipment to display Doppler spectrum moments (e.g., mean velocity) in real time (Fig. 4.6). NSSL radars are among the few with characteristics to facilitate Doppler observations of severe storms. And they have the sensitivity for measurement of Doppler spectra of echoes from clear air on warm days.

Other agencies and facilities in this area give important aids to the NSSL observational program. For example, more than 200 recording raingages are located in a section of the Washita River drainage area, 35 to 90 km west of Norman. These gages, operated by the Agricultural Research Services, USDA, Chickasha, Oklahoma, provide records valuable for studies of relationships between radar echo reflectivity and surface rainfall.

Max Westheimer Field, where NSSL Headquarters is located, provides a convenient base for small aircraft. Tinker Air Force Base, 15 miles NNE of NSSL Headquarters, is base for most larger aircraft deployed by NOAA and USAF for use in the observation program. For example, aircraft of NOAA's Research Flight Facility and USAF F–100 and F4C storm-penetrating aircraft are based customarily at Tinker AFB for Oklahoma operations (Fig. 4.7).

NSSL operates a substantial computing center to support basic research, data acquisition, and data quality control. The principal computer was acquired October 1972; this is an SEL 8600 (Fig. 4.8) with a random access core containing 128,000 32-bit words, two 24-megabyte discs, four 7-track tape drives, a teletype console, a 1000 card/min reader, and a 600 line/min printer. Contents of the magnetic tapes on which practically all radar and tower data is archived, can be listed, combined, or rearranged with NSSL's IBM 1401 tape handling system. NSSL's Calmagraphic II X–Y reader and plotter facilitate graphic portrayal of data fields. During summer 1976, we completed a remote terminal to link NSSL to fifth-generation computers for studies that require a larger random access core than the SEL 8600 provides.

5. Contracts, Grants

Some funds administered at NSSL support investigations at other institutions, closely related to NSSL objectives. Funds are made available to an investigator as a grant to the institution, usually a university, which employs him. Grants are in two categories (both NSSL categories are denoted Type II in the Environmental Research Laboratories). In one case, there is a definite tie-in or logical extension

Table 5.1 NSSL Grants FY–76

TITLE/GRANT NUMBER	STARTING & TERMINATING DATES	INSTITUTION	AMOUNT	PRINCIPAL INVESTIGATOR	NSSL COGNIZANT SCIENTIST
Severe Storms Research 04–6–022–44011	9/1/76 to 8/31/76	Florida State University	$6,000 (8C370401)	J. J. Stephens	Peter S. Ray
Investigations of the Relations of Air Motion and Microphysical Process to the Distribution of Precipitation Associated with Cumulus Updrafts 04–5–022–1	7/1/75 to 6/30/76	Massachusetts Institute of Technology	$18,100 (8C370401)	Pauline Austin	Edwin Kessler
Tropical Cloud Bands and Large-Scale Deformation Fields—04–5–022–9	10/8/74 to 5/31/77	Massachusetts Institute of Technology	$4,000 (8C370410)	Fred Sanders	Edwin Kessler
Stability of Tornado-like Vortices—04–6–022–44004	9/1/76 to 8/31/76	Ohio State University	$20,000 (8C370401)	O. R. Burggraf and M. R. Foster	R. P. Davies-Jones
A Study of the Diurnal Variation of the Low-Level Jet as a Geostrophic Adjustment Process 04–6–022–44002	7/1/75 to 6/30/76	University of Oklahoma	$6,000 (8C370401)	R. L. Inman	Ronnie Alberty
An Investigation of the Boundary Layer of an Atmospheric Mesoscale Vortex—04–6–022–44003	7/1/75 to 6/30/76	Saint Louis University	$7,500 (8C370401)	G. V. Rao	Ronnie Alberty
Severe Storms Research 04–6–022–44001	7/1/75 to 6/30/76	University of Toronto	$5,200 (8C370401)	Roland List	Joe Schaefer
Analysis of Three-Doppler Radar Data 04–6–022–44023	3/1/76 through 2/28/77	University of California at Davis	$5,540 (RC370503-NRC)	Kit Wagner	Peter Ray
A Severe Storm Forecast and Intercept Project 04–6–022–44024	4/15/76 to 6/15/76	University of Oklahoma	$4,614 (RC370503-NRC)	J. F. Kimpel	Ronnie Alberty
Severe Local Storms 04–5–022–15	7/1/75 to 8/31/76	Purdue Research Foundation	$6,000 (RD840520-ERDA)	E. Agee	Ronnie Alberty
Engineering Evaluations of Tornado Events 04–4–022–38	7/1/75 to 8/31/76	Texas Tech University	$20,000 (RC370503-NRC)	J. E. Minor	R. P. Davies-Jones
	TYPE I GRANTS OF INTEREST TO NSSL				
Multiple Doppler Radar Study of Severe Storms	3/1/76 to 2/28/77	University of Chicago	$16,000 (RA0000)	R. C. Srivastava	Peter Ray
	TYPE I CONTRACTS OF INTEREST TO NSSL				
Oklahoma Radar Operations and Related Research 03–6–022–35148	7/1/75 to 6/30/77	University of Illinois at Champaign-Urbana	$33,000 (RA0000)	E. A. Mueller	Peter Ray

of work being done in-house. Contracts and grants in this category are used because the work is thought likely to provide definite, immediate steps forward in an important area. These contracts and grants provide funds for both direct and indirect costs.

A second type of grant within NSSL intends direct assistance to graduate students guided by a professor in the area enclosed by our general mandate. We venture to provide the basis for a stipend with a minimum of technical evaluation or administrative fuss. Grants are awarded on a basis of one to each applying institution with a strong meteorology department, subject to availability of funds. In addition to aiding storm-oriented interest in universities, our grants help maintain constructive exchanges of many kinds between the academic community and NSSL scientists.

Beyond grants provided by NSSL-administered funds, NSSL staff participate in evaluating proposals competing for funds administered from ERL Headquarters in Boulder, the National Science Foundation, and elsewhere. A small number of (Type I) proposals funded by the ERL path relate immediately to NSSL.

For the 1976 fiscal year ended July 1, 1976, grants in force funded by NSSL are listed in Table 5.1. Also given are one contract and one grant for NSSL's three-Doppler radar program, funded from ERL Headquarters in Boulder. Grants funded during the FY–76 transitional quarter are listed in Table 5.2.

Contracts are arranged with various organizations to purchase or lease specific items or services. For example, locations on the KTVY tower are leased at an average cost of about $150 per month (20¢ per

Table 5.2 NSSL Grants Transitional Quarter

TITLE / GRANT NUMBER	STARTING & TERMINATING DATES	INSTITUTION	AMOUNT	PRINCIPAL INVESTIGATOR	NSSL COGZIZANT SCIENTIST
Storm Modeling and Use of Observational Data 04–6–022–44034	8/1/76 to 7/31/77	University of Illinois at Urbana	$6,000 (8C370408)	Robert B. Wilhelmson	Peter S. Ray
Investigations of the Relations of Air Motion and Microphysical Processes to the Distribution of Precipitation Associated with Cumulus Updrafts 04–5–022–1	Continuation through 12/31/76	Massachusetts Institute of Technology	$10,850 (8C370410)	Pauline Austin	Edwin Kessler
Severe Local Storms 04–6–022–44035	9/1/76 to 9/30/77	University of Oklahoma	$40,623 (8C370410)	Rex L. Inman	Ronnie Alberty
Research and Development of a Weather Radio Echo Signal Simulator 04–6–022–44033	7/1/76 to 8/31/77	University of Oklahoma	$16,893 (8C370403)	Gene B. Walker	Richard Doviak
Severe Local Storms 04–5–022–15	Continuation to 8/31/77	Purdue University	$6,000 (8C370408)	Ernest M. Agee	Ronnie Alberty
An Investigation of the Boundary Layer of an Atmospheric Mesoscale Vortex 04–6–022–44003	7/1/76 to 5/31/77	St. Louis University	$7,500 (8C370408)	G. V. Rao	R. P. Davies-Jones
Mobile Homes in Windstorms: Engineering Assessment and Preparedness Concepts 04–4–022–38	Continuation to 11/30/76	Texas Tech University	$6,620 (8C370410)	Joseph Minor	R. P. Davies-Jones
Hail and Severe Storm Modeling 04–6–022–44001	7/1/76 to 6/30/77	University of Toronto	$6,500 (8C370408)	Roland List	Stephan Nelson
Dynamical Model of Gust-Fronts 04–6–022–44031	7/1/76 to 6/30/77	University of Oklahoma	$11,905 (RC360205)	Yoshi K. Sasaki	Ronnie Alberty

month per foot above the ground). The U. S. Army and U. S. Air Force are reimbursed for expendable supplies and per diem costs incurred in connection with special rawinsonde observations (approximately $85,000 for about 1000 ascents distributed over eight locations and 33 days during spring 1976—this cost includes some data processing). ACTS, Inc. receives approximately $35,000/year to pay for NSSL's computer operations to the extent of about 100 person-hours/week throughout the year.

6. Principal Accomplishments

In twelve years since its establishment in Norman, Oklahoma, NSSL has developed broadened understanding of severe storms and provided much valuable methodology to both the scientific community and public users of meteorological information. We cite the following activities in applications:

(A) NSSL has been in the forefront in development of new techniques for acquisition, processing, display, and analysis of weather radar data. Radar contour mapping equipment developed in Oklahoma by Roger Lhermitte and Dale Sirmans, starting in 1965, was an important stimulus for procurement of video-integrating processors now installed widely with radars of the National Weather Service (Fig. 6.1). In 1973, NSSL was first with real time displays of velocity contours derived from Doppler radar data. Numerous papers on digital processing of radar echo data to correlate radar intensity with rainfall, and systematic extrapolation of storm positions for flash flood forecasting and storm warning help energize NWS programs D/RADEX and RADIT, which develop operational applications of digital radar data. (Some historical details have been provided by Mr. Sirmans, NSSL's Chief Engineer; see Appendix B.)

References

Brandes, E., 1975: Optimizing rainfall estimates with the aid of radar. *J. Appl. Meteor.*, **14**(7), 1339–1345.

Kessler, E. and K. E. Wilk, 1968: Radar measurement of precipitation for hydrological purposes. World Meteorological Society, International Hydrological Decade, Report No. 5, 46 pp.

Lhermitte, R. M. and E. Kessler, 1965: A weather radar signal integrator. *Proceedings*, International Conf. on Cloud Physics, Tokyo and Sapporo, Japan, 302–308.

Sirmans, D., W. L. Watts, and J. H. Horwedel, 1970: Weather radar signal processing and recording at the National Severe Storms Laboratory. *IEEE Trans. on Geoscience Electronics*, **GE-8**(2), 88–94.

Sirmans, D. and R. J. Doviak, 1973: Pulsed Doppler velocity isotach displays of storm winds in real time. *J. Appl. Meteor.*, **12**(4), 694–697.

Sirmans, D. and R. J. Doviak, 1973: Meteorological Radar Signal Intensity Estimation. NOAA Tech. Memo. ERL NSSL–64, 80 pp.

Wilson, J. W., 1970: Integration of radar and raingage data for improved rainfall measurement. *J. Appl. Meteor.*, **9**(3), 489–497.

(B) Turbulence in severe thunderstorms and performance of both airborne and ground based radars have been explored systematically at altitudes from 5,000 to 40,000 ft and statistical relationships discovered that connect turbulence experienced by an aircraft with the maximum reflectivity in storms and distance of storm cores from the aircraft. Turbulence relationships identified at NSSL from a program managed by Mr. Jean Lee form the basis for FAA Advisory Circular 00–24, a counsel to the aviation industry on flight safety near severe convective storms. A continuing program with support from the Federal Aviation Administration focuses on thunderstorm gust fronts and on use of Doppler radar to depict turbulent areas more definitively.

References

Barclay, P. A. and K. E. Wilk, 1970: Severe Thunderstorm Radar Echo Motion and Related Weather Events Hazardous to Aviation Operations, ESSA Tech. Memo. ERL NSSL–46, 63 pp.

Burnham, J. and J. T. Lee, 1969: Thunderstorm turbulence and its relationship to weather radar echoes. *AIAA J. Aircraft*, **6**(5), 438–445.

FAA Advisory Circular 00-24, 1968: Thunderstorms. June, 6 pp.

Goff, R. C., 1976: Vertical structure of thunderstorm outflows. *Mon. Weather Rev.*, **104**(11), 1429–1440.

Kessler, E., J. T. Lee, and K. E. Wilk, 1965: Associations between aircraft measurements of turbulence and weather radar measurements. *Bull. Amer. Meteor. Soc.*, **46**(8), 443–447.

Merritt, L. P., 1969: Comparison of airborne and ground based weather radars. *J. Appl. Meteor.*, **8**(6), 963–974.

Wilk, K. E., J. K. Carter, and J. T. Dooley, 1969: Detection and Presentation of Severe Thunderstorms by Airborne and Ground Based Radars, ESSA Tech. Memo. ERL NSSL–43, 56 pp.

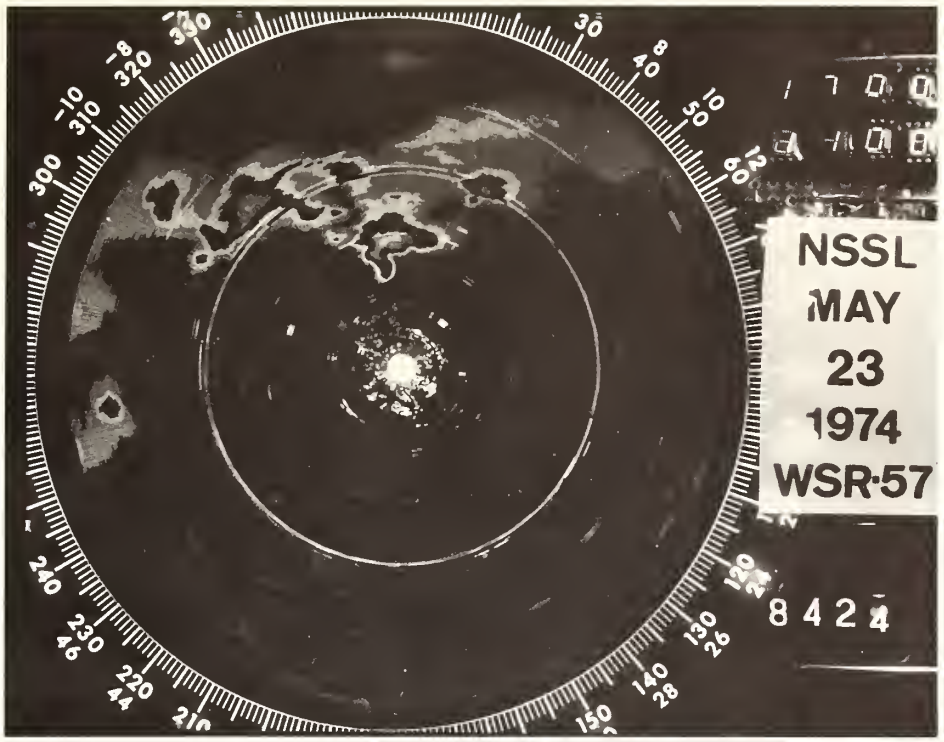


Figure 6.1 Radar echo contour presentation of an east-west oriented squall line. Range marks are at intervals of 40 km. The "hook echo" north of the radar comes from a tornadic storm. The scattered short arcs indicate the locations of aircraft equipped with beacons for easy detection by radar.

(C) With support from the Energy Research and Development Administration and the Nuclear Regulatory Commission, intensive investigations of tornado wind speeds have been undertaken. Estimation of wind speed involves tornado damage surveys by well qualified engineers supported by contracts and grants, photogrammetric reduction of tornado motion picture films collected by NSSL Storm Chase teams and the public, and analyses grounded in meteorology theory. There has been a remarkable convergence of well-based theory with observations, most estimates of maximum tornado winds now being in the neighborhood of 250–300 mph, rather than up to 500 mph earlier proposed. In this there are vast implications for industries, such as the nuclear industry, involved with structures whose dangerous contents would spread havoc if dispersed. A complementary public information program, largely through the American Meteorological Society and the National Weather Service, promotes adoption of rational building codes and zoning ordinances.

References

Golden, J. H. and D. Purcell, 1976: Photogrammetric Velocities for the Great Bend, Kansas Tornado: Accelerations and asymmetries. *Preprints*, Ninth Conf. on Severe Local Storms, Norman, Oklahoma, Oct. 21–23, 1975, Am. Meteorol. Soc., Boston, Massachusetts, 336–343.

Mehta, K. C., J. E. Minor, J. R. McDonald, B. R. Manning, J. J. Abernethy, and U. F. Koehler, 1975: Engineering aspects of the tornadoes of April 3–4, 1974. Final Report. National Academy of Sciences, 110 pp.

Policy Statement of the American Meteorological Society on Tornado Detection, Tracking, and Warning; Policy Statement of the American Meteorological Society on Mobile Homes and Severe Windstorms, 1975. *Bull. Am. Meteorol. Soc.*, **56**(4), 464–467.

(D) NSSL's Doppler radars have shown that tornado indicators may appear without the hook echo so often associated with tornadoes. The mesocyclone velocity signature, 5 to 10 km in diameter, not only persists during storm evolution, but also holds promise as a tornado warning tool. Five years of NSSL data reveals 40 mesocyclone signatures within 115 km of NSSL—at least 24 associated with tornadoes. At no time has the data shown a tornado not preceded by a mesocyclone signature. The average lead time of 36 min in the NSSL data has important implication for more timely tornado warnings.

References

Brown, R. A. and L. R. Lemon, 1976: Single Doppler radar vortex recognition: Part II—Tornadic vortex signatures. *Preprint*, Proceedings of the 17th Radar Meteorol. Conf., Seattle, Washington, Oct. 26-29, 1976. Am. Meteorol. Soc., Boston, Massachusetts, 104–109.

Burgess, D. W., L. R. Lemon, and R. A. Brown, 1975: Tornado characteristics revealed by Doppler radar. *Geophys. Res. Letters*, **2**(5), 183–184.

Burgess, D. W., 1976: Single Doppler radar vortex recognition: Part I—Mesocyclone signatures. Proceedings of the 17th Radar Meteorol. Conf., Seattle, Washington, Oct. 26–29, 1976. Am. Meteorol. Soc., Boston, Massachusetts, 97–103.

Sirmans, D., R. J. Doviak, D. W. Burgess, and L. R. Lemon, 1974 Real time Doppler isotach and reflectivity signatures of a tornadic cyclone. *Bull. Am. Meteorol. Soc.*, **55**(9), 1126–1127.

Among NSSL's contributions toward better understanding of weather phenomena, we cite the following areas:

(A) Tornado vortices: Laboratory experiments at NSSL have illuminated contrasting conditions favoring formation of single and multiple vortices within a single main updraft (Fig. 6.2). Other features of tornadoes reproduced are a bulging deformation on the vortex core and a characteristic surface pressure profile. The radius of the turbulent vortex core is shown to be a function primarily of swirl ratio (ratio of tangential to vertical air velocities).

References

Davies-Jones, R. P., 1973: Dependence of core radius on swirl ratio in a tornado simulation. *J. Atmos. Sci.*, **30**, 1427–1430.

Ward, N. B., 1972: The exploration of certain features of tornado dynamics using a laboratory model. *J. Atmos. Sci.*, **29**(6), 1194–1204.

(B) Dryline mechanics: The dryline of the U. S. West Central Plains has long been known as a favorable place for severe convective development. A descriptive model of dryline formation and movement postulates that dryline motion represents eastward propagation of the mixing zone between moist and dry air. The postulate is supported by a numerical model whose behavior closely fits observations. Other dryline manifestations indicate a storm trigger mechanism explained by mutual diffusion of heat and moisture across the dryline. This storm triggering effect compares with vertical currents that arise in the ocean where relatively cold fresh water lies next to warm saline water.

References

Schaefer, J. T., 1974: A simulative model of dryline motion. *J. Atmos. Sci.*, **31**(4), 956–964.

Schaefer, J. T., 1974: The life-cycle of the dryline. *J. Appl. Meteorol.*, **13**(4), 444–449.

(C) Evolution of atmospheric water distributions: A comprehensive theory treats connections between distributions of atmospheric wind and water, interprets many observations on precipitation, and provides inderstanding of interactive functions of thermal buoyancy and condensate loading of air columns. Methods used in this work for simple representation of microphysical processes associated with precipitation formation, have been adapted widely for use in numerical simulations of convection.

References

Kessler, E., 1969: on the continuity of water substance in atmospheric circulations. *Meteorological Monographs*, **10**(32), 84 pp.

Kessler, E., 1975: Model of precipitation and vertical air currents. *Tellus*, **26**(5), 519–542.

(D) Thunderstorm morphology: Extensive analysis of thunderstorm data define storm airflows, thermal structure, and precipitation distribution of large storms typically 20–40 km across. Doppler radar is now revealing details of air flow and associated precipitation in storm interiors, and including the three-dimensional configuration and evolution of the tornado vortex itself (Fig. 6.3).

References

Brandes, E. A., 1975: Severe thunderstorm flow characteristics revealed by dual-Doppler observations: 6 June 1974. *Preprints*, Ninth Conf. on Severe Local Storms, Norman, American Meteorological Society, 85–90.

Barnes, S. L., Editor, 1974: Papers on Oklahoma thunderstorms, April 29–30, 1970. NOAA Tech. Memo. ERL NSSL–69, 233 pp.

Davies-Jones, R. P., D. W. Burgess, and L. R. Lemon, 1975: Analysis of the 4 June 1973 Norman tornadic storm. *Preprints*, Ninth Conf. on Severe Local Storms, Norman, American Meteorological Society, 384–388.

Fankhauser, J. C., 1971: Thunderstorm-environment interactions determined from aircraft and radar observations. *Mon. Weather Rev.*, **99**(3), 171–192.

Hammond, G. R., 1967: Study of a left moving thunderstorm of 23 April 1964. Institutes for Environmental Research Tech. Memo. NSSL–31, 75 pp.

Ray, P. S., 1976: Vorticity and divergence field within tornadic storms from dual-Doppler observations. *J. Appl. Meteor.*, **15**(8), 879–890.

Ray, P. S., R. J. Doviak, G. B. Walker, D. Sirmans, J. Carter, and W. Bumgarner, 1975: Dual-Doppler observations of a tornadic storm. *J. Appl. Meteorol.*, **14**(8), 1521–1530.

Another kind of contribution of no less importance is NSSL's provision to the meteorological community of a versatile facility for comprehensive observations on severe storms. The NSSL facility has been used on a cooperative basis by scientists and students from all over our nation and from several other countries who would otherwise have poor prospects for nourishing their germinal ideas on severe storms with relevant data. During the 15 months of FY–76 and the transition quarter, NSSL staff responded to 64 requests for data or systems support software from investigators outside the Laboratory, and was host to 35 scholars who visited NSSL from one to several days or months. The Ninth

Figure 6.2 Single and double vortices and other vortex combinations can be produced under controlled laboratory conditions in an apparatus developed by the late Neil Ward.

AMS Conference on Severe Local Storms, with nearly 200 participants, was held in Norman during October 1975. During the approximately 60-day spring period traditionally set aside for intensive observations on storms, participation by many federal agencies and university groups is represented by staff of those organizations and by special equipment.

All the contributions to the literature during FY–76 by NSSL staff are listed in Appendix C.

7. Current Program

There have always been two very closely related foci of emphasis at NSSL: basic research, a search for better understanding of fundamentals; and applications, the use of what we know to improve storm forecasting and warning operations in the National Weather Service. Both share a common wellspring in recent electronic technology which carries vast capabilities in rates of data acquisition, processing, analysis, and communication. Both share today a strong involvement with Doppler radar. The distinction between the two is often quite properly blurred. The pages immediately following describe some of the important problems that have recently engaged us.

7.1 Multiple Doppler Observations of Wind Fields

NSSL's own Doppler radar systems are positioned on a 42 km NW–SE baseline, to allow construction of a three-dimensional field of wind. The NSSL Doppler radars measure velocity along the line of sight at 762 locations in range, and (typically) one degree intervals of azimuth. In approximately 1 minute, target velocities at nearly 300,000 locations within 115 km of the radar, can be recorded on magnetic tape at each radar. During the spring season 1976, a contract provided for a third Doppler radar to be brought to Anadarko, Oklahoma, from the Illinois State Water Survey, Urbana, Illinois. Since each radar measures the target velocity along the line of sight only, rather complex mathematical analysis is necessary to combine the data and provide estimates of eastward, northward, and upward air currents everywhere in a large space. And, of course, it is of great importance to know the accuracy of the wind data so derived. Peter Ray of NSSL treated cases of both two and three radars, each providing estimates of the wind component along radials from the radar sites. The estimated fall speed of precipitation, which when present contributes with the wind itself to the perceived radial winds, also enters the analysis.

Distribution of estimated errors in the wind field near the Earth's surface are illustrated in Fig. 7.1. Note that the errors over most of the area associated with three Doppler radars are less than half the errors associated with two Doppler radars. In addition, use of three Doppler radars provides a much larger area of coverage in which the errors are small and more assurance that usable data will be collected even in case one radar malfunctions.

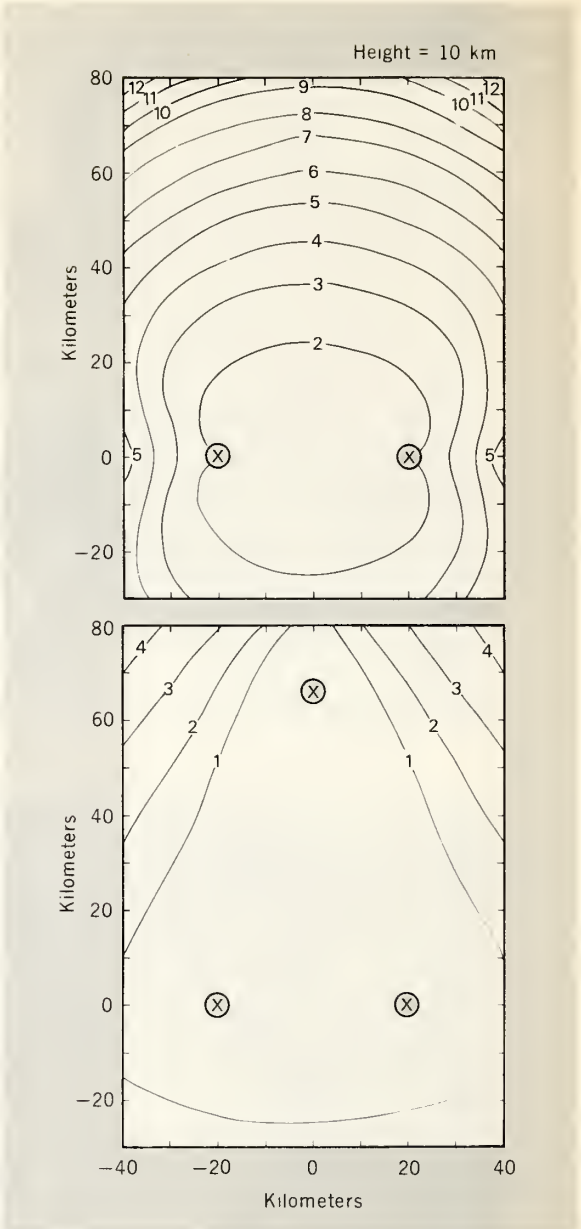


Figure 7.1 Comparison of two- and three-Doppler error analysis. The standard deviation in meters/second of windspeed estimates is shown at 10-km height for radar locations indicated by a circled "X". Interpolated radial velocity and terminal velocity error variance were assumed to be 0.1 and 1.0 $(m/s)^2$, respectively.

7.2 Pre-Cloud and Cloud Research at NSSL

Systematic measurement with NSSL's Doppler radars shows that accurate (1–2 m s^{-1} rms error) velocities within the lowest kilometer in clear air can be obtained typically to ranges of 60 km. It seems that densely spaced two-Doppler data can provide horizontal wind over large areas prior to precipitation

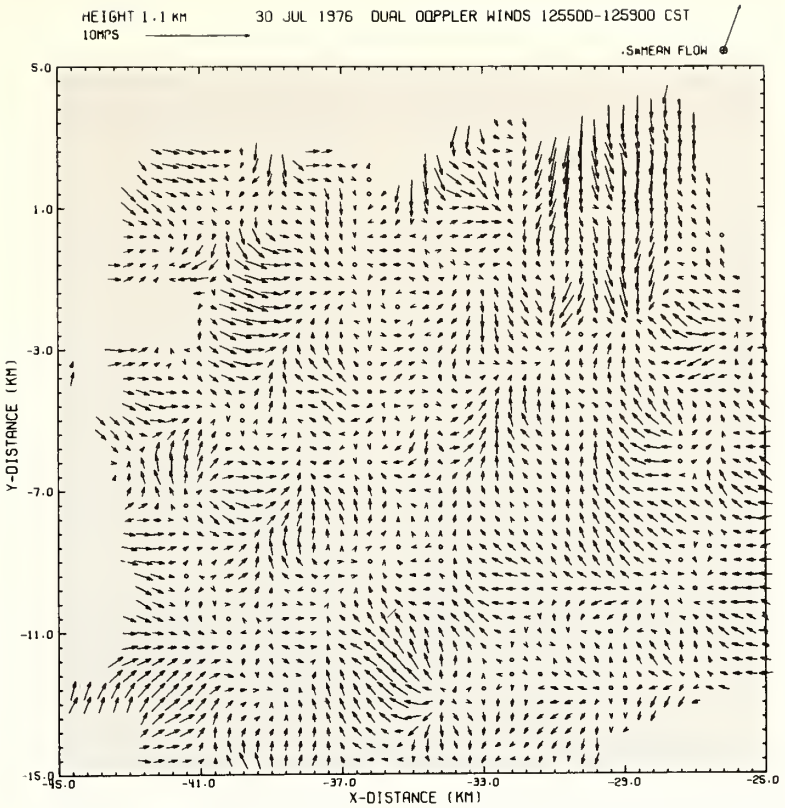


Figure 7.2 Airflow on a clear day relative to the area average flow. This is based on synthesis of radial velocity data from Doppler radars at Norman and Cimarron Field, Oklahoma. Half the average flow is indicated by the vector in the upper right hand corner.

development (Fig. 7.2). Specifically, it should be possible to analyze gust fronts and turbulent regions, but the most important application of clear-air measurements will probably be to the initial stage of cumulus development in severe local storms.

Experiments conducted during 1976 by R. J. Doviak and Dusan Zrnic indicate that NSSL's Doppler radars have capability to map, without chaff*, the development of severe storms prior to and during the small cumulus stage. Because reflective chaff is not required, we can track the growth of natural reflectivity and relate the reflectivity distribution to updrafts. A feature that distinguishes a monster storm from an ordinary thunderstorm is that updraft becomes persistent and jet-like instead of possessing several seemingly unorganized thermals.

Some outstanding questions are the following:

When are updrafts invigorated, and what relationships exist among updrafts, precipitation, and downdrafts in the various stages of a thunderstorm?

Can we identify a transition from turbulent thermals to the organized plume of an incipient storm?

Will Doppler data (spectrum width) define a sheath of mixed upper level air that bounds the updraft column and inhibits its growth? Can we characterize this sheath (i.e., diffusion length, thickness, etc,)?

Are persistent plume-like updrafts associated with the arrival of precipitation at the ground?

There should be two stages of measurement: clear air and weak echoes, and strong echoes.

Returns from the clear and cloudy (but possibly nonprecipitating) environment produce signals that are near and below receiver noise level. Strong echoes produce signals that may be a hundred or more times stronger than receiver noise. Thus, we require two modes of data collection and special precaution to avoid contamination of data by spurious signals. High resolution photographs from satellites should provide a major contribution to analysis.

*Also called window, chaff is a vast number of fine metallized needles, which by diffusion fill a substantial airspace and provide a continuous radar target.

7.3 Studies of the Moist Boundary Layer With a Turbulence Closure Model

The structure and development of the layer near the Earth's surface (planetary boundary layer, PBL) has been the subject of extensive analytical and numerical study because this is where we live, and it is the place where the atmosphere's principal energy is first received as heat and then distributed.

There has already been extensive study of dry boundary-layer processes such as mixing through the stable layer that ordinarily caps the first kilometer. However, Steve Burk, National Research Council Postdoctoral Associate at NSSL, has included moisture in his study of boundary-layer structure and development. An appropriate model including both temperature and moisture would provide accurate predictions of the radar reflectivity of clear air, and hence of our ability to examine wind distributions in clear air with Doppler radar, as shown in Fig. 7.2.

Dr. Burk's work employs an advanced technique known as second order turbulence closure to provide a more accurate description of the turbulent processes which produce transport and mixing of heat and moisture in the PBL. He first examined a case in which the lower boundary condition requires surface moisture to vary with surface temperature. Evolution of the moisture distribution during calculations representing the first 24 h of model time is displayed in Fig. 7.3. The initial moisture distribution is shown in detail by the curve at the right in the figure. A considerable initial moisture lapse above 0.5 km is assumed, consistent with early morning observations. Above the surface boundary layer, the model describes convective development of a well mixed moist layer which reaches a height of approximately 1500 m by late afternoon. Thus, moisture is well mixed and almost evenly distributed during the afternoon despite dry air entrainment at the top and surface moisture influx from below.

Figure 7.3 also contains other significant information. For example, the daily variation in humidity at low levels shows a double wave structure (having minima in the early morning and midafternoon). The early morning minimum is associated with the surface temperature minimum, whereas the midafternoon minimum results from mixing of the moist lower layer with the dry layer above. This vertical redistribution of the water vapor content can increase the atmosphere's stability (resistance to overturning) and thereby reduce the likelihood of midafternoon showers.

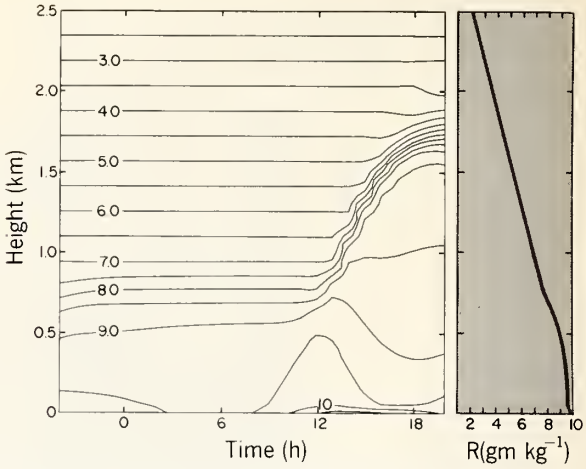


Figure 7.3 Evolution of the specific humidity field (gram/kg) during the first 24 hr of a numerical experiment designed by Stephen Burk. The initial specific humidity distribution is shown at the right.

In other experiments, realistic development of a single midafternoon minimum in low lture content is found for a dry, desert-like climate; while an increase of moisture with height associates with dew formation. Thus, it appears that this turbulence closure model is capable of providing considerable insight into processes that determine distributions of moisture and temperature in the planetary boundary layer, as well as providing a support to use of Doppler radar for acquiring direct observations of wind distribution in that layer.

7.4 Precursor Conditions for Storm Development

Textbooks commonly relate severe thunderstorms to large-scale upward vertical air motion imposed over a region of strong temperature contrast. We know now that this description is inadequate, for statistical analysis work of the Techniques Development Unit, National Weather Service has shown almost no correlation between large-scale positive vorticity advection (PVA, associated with vertical air motion) at 500 mbar and severe thunderstorm occurrences. We now believe that thunderstorm forcing responds to smaller scale flows which are difficult to detect with the present observation system.

Clues to the structure of the vertical velocity field preceding tornadic development have been found. One ongoing project at NSSL by Dr. Davies-Jones and Dr. Schaefer continues studies of atmospheric soundings taken within about 60 nmi and 90 min of

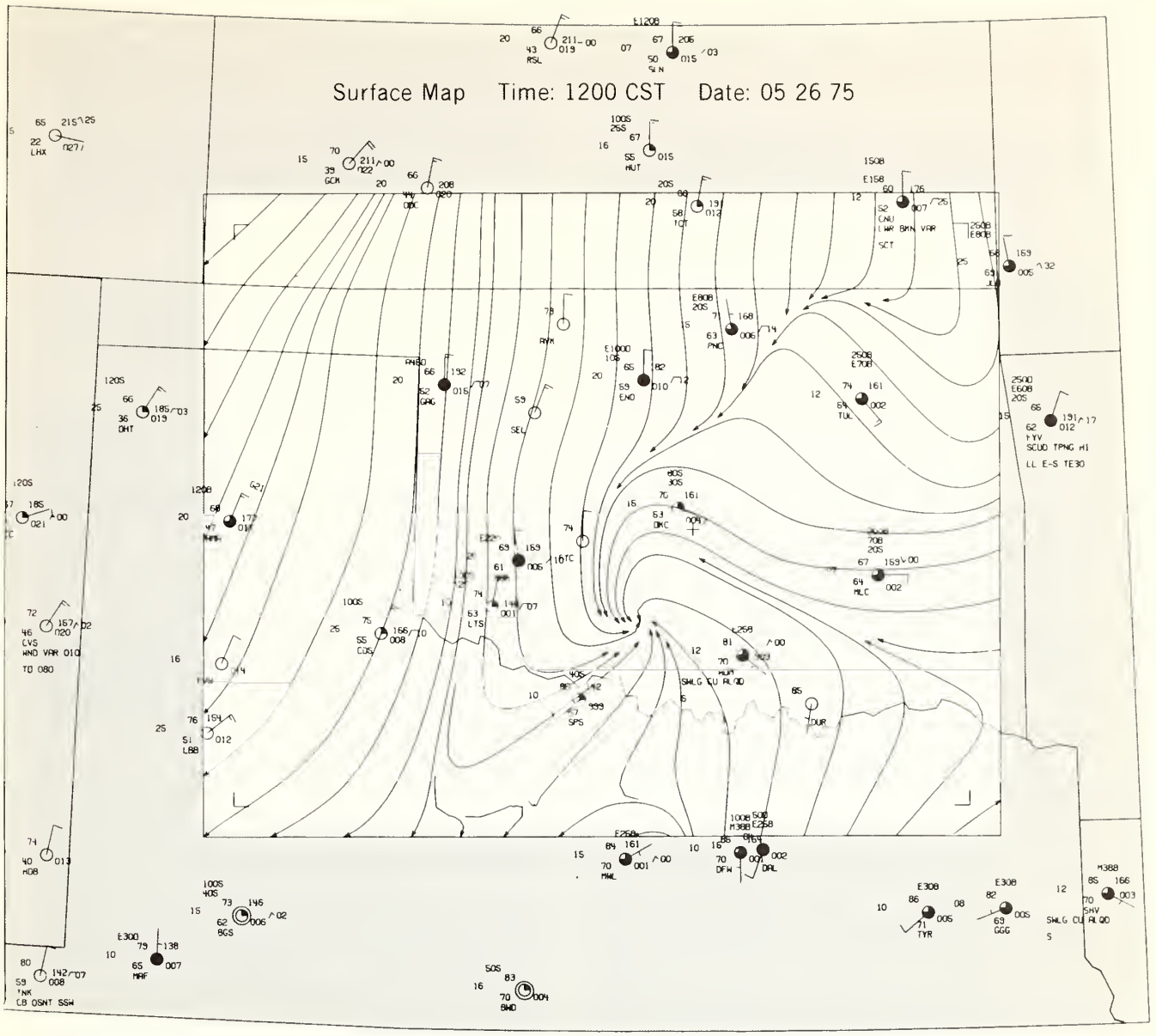


Figure 7.4 Weather map for area centered on Oklahoma, plotted and analyzed by computer, three hours before severe thunderstorm development. The line of convergence extending northeast marks a southward moving cold front. Additional computer analysis reveals a center of moisture convergence nearly coincident with the center of rotation and the locus of storm formation.

tornadoes. First indications confirm a previous finding that the low-level inversion lifts only in a very localized region near the storm. A further and somewhat surprising result is the consistent presence of mid- and upper-tropospheric warming several hours before radar echoes appear. While these findings are tentative, we have quite a lot of confidence in them.

The above facts are consistent only if larger scale vertical motion is downward before severe storm development. To verify this theory, a technique to compute the vertical velocity on scales compatible with the Weather Service rawinsonde network is being developed. Observations are consistent with small perturbations with accompanying localized regions of positive vertical velocity in a generally sinking upper-level flow. Localized regions of surface moisture convergence (Fig. 7.4) that slowly progress eastward (less than 30 km/h) and finally produce severe weather are consistent surface reflections of a wave in mid-troposphere with a 500-km wavelength. Such features obviously cannot be detected with the 400-km grid spacing now used in the upper air sounding network, but inferences towards the necessary conditions for severe storm development can be drawn from this research.

7.5 Thunderstorm Structure, Evolution, and Environment Interaction

The air in strong thunderstorm updrafts tends to maintain the small horizontal speed of low altitudes, and hence acts as an obstacle to the fast environment flow in mid levels (4–8 km). The more intense the updraft, the stronger its function as a block on the environmental flow. When mid-level winds are as strong as 65 kn, anticyclonic (clockwise) vortices have been observed to form within storm radar echoes and move downstream from the storm. What is the significance of these anticyclonic wake vortices? The anticyclonic vortex seems to form when a thunderstorm updraft begins to rotate cyclonically and severe weather starts. Leslie Lemon found such an association in six severe storms and noted an analogy to the "starting vortex" investigated in the theory of airfoils.

In a study completed by Rodger Brown, Don Burgess, and Leslie Lemon, Doppler radar data have indicated an unanticipated result. As rotation in the mesocyclone, parent to the tornado, increases beyond a certain point and tornado production is favored or occurs, the updraft is disrupted. We speculate that the increased energy required to drive the spinning flow, leaves less energy available to drive the vertical updraft flow, and the storm top therefore begins to collapse.* This can ultimately lead to cessation of the updraft and of the tornado itself. This hypothesis requires formulation as a mathematical model which may help us discover different conditions that tend to favor transient and enduring classes of tornadoes.

7.6 Investigation of Tornadic Storms With Doppler Radar

The continuum of observations provided by Doppler radar yields information on temporal and spatial scales previously unavailable. Studies on tornadic storms show that rotation in the main intense updraft, the updraft mesocyclone, is characteristic of their early development. Damaging surface winds and tornadoes are closely related to th existence of these circulations at ground levels.

*Such a theory has found a highly practical application in firehoses which use a spin-creating nozzle as a valve.

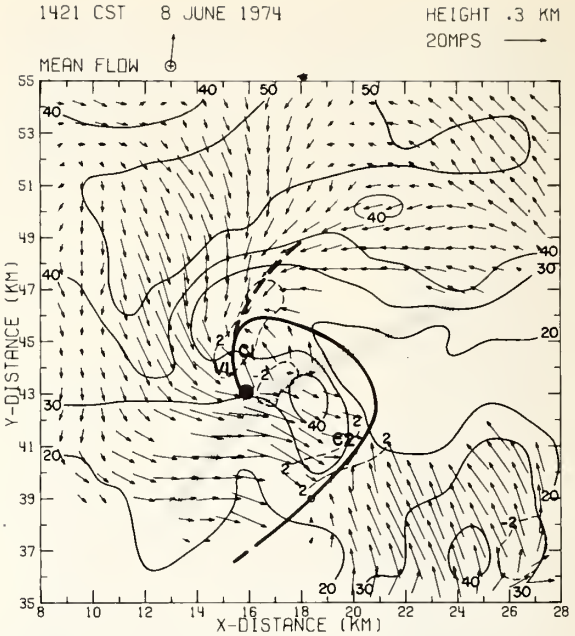


Figure 7.5 Horizontal airflow relative to the area average flow in a tornadic thunderstorm. Labeled contours represent the radar reflectivity, the shaded swath represents tornado damage, and the heavy solid and dotted lines represent gust fronts. Centers of vorticity and convergence are represented by V and C's. A few dashed lines show vertical air velocities in meters/sec.

Rotation first appears aloft (2- to 5-km elevation) along a strongly sheared and convergent zone between air entering both forward and rear storm sectors. Such shear zones have been observed to extend lengthwise along squall lines and to exhibit mesocyclones at intervals. It is believed that convective processes (e.g., updraft-downdraft interaction, angular momentum transport, and vertical stretching) dominate both mesocyclone and tornado development but that shearing instability may be important in the formative stage.

With time the mesocyclone lowers and a pronounced gust front, reminiscent of synoptic-scale wave cyclone development, evolves at the surface. Note the psuedo cold front extending southward and diffuse warm front extending northward in Fig. 7.5, prepared by Edward Brandes in connection with his study of the storm of June 8, 1974, in Oklahoma City. Tornado genesis (location indicated with ⊗) is along the major horizontal axis of the mesocyclone. Dissolution occurs when the tornado becomes detached from the principal updraft.

Although the Doppler radar data provide a description of tornado evolution, actual physical bases for tornado development are still rather mysterious today. Effective analysis of the forces involved will include consideration of thermodynamic data, i.e.,

temperature, pressure, and moisture content at closely spaced intervals. Another approach will involve simultaneous consideration of winds and target radar echo intensity—the latter indicates the density of precipitation and hence estimates a component of the buoyancy force which influences air motion.

7.7 Tornado Dynamics Research at NSSL

Field observations, photogrammetric analyses, and models (both theoretical and experimental) are being used by Robert Davies-Jones to elucidate the dynamics of tornadoes and their parent thunderstorms (Fig. 7.5).

Results to date indicate that intense tornadoes have maximum velocities in the neighborhood of 100 m s^{-1}. Extreme vertical velocities of 60 m s^{-1} have been observed in the lowest 100 m above the ground. Anti-cyclonic tornadoes do occur. Tornadoes generally form in precipitation-free, lightning-free regions of the storm. Strong tornadoes form beneath wall clouds (i.e., discrete lowerings of cloud base) and undergo morphological changes in accordance with a well-defined life cycle. Coincidental with the morphological changes are corresponding changes in surface debris configurations, path width, and damage severity. Circulation is not always evident in surface debris and damage during the shrinking and decay stages of the tornadoes' life (in some cases during the entire lifetime). Strong radial inflow next to the ground during the shrinking and decay stages have also been inferred from damage surveys (Fig. 7.6). The significance of Doppler radar mesocyclone and tornado signatures have been verified by visual field observations. Tornadoes often form in favored local regions which can be identified a few hours in advance. The tornado is usually located on the right rear flank of the storm close to the location where actively growing storm towers merge with the parent cumulonimbus cloud. Large hail often falls a few kilometers ahead of and to the left of the tornado and a thin curtain of precipation often wraps cyclonically around the tornado, probably accounting for hook echo radar signatures (Fig. 6.1). This phenomenological distribution helps guide us toward improved description and understanding of the air flow and associated processes in tornadic storms.

Figure 7.6 Analysis of the pattern of damage produced by tornadoes in grass, trees, and structures enables important conclusions to be derived about the wind that produced the damage and about construction practices.

7.8 Storm Hazards to Aviation

Thunderstorms are the principal meteorological hazard to aviation today, and NSSL continues to develop improved descriptions of the thunderstorm aviation hazard and improved techniques for forecasting and depicting storms. This project has been managed by J. T. Lee since its inception.

During the mid-1960's, nearly 1000 controlled instrumented flights into thunderstorms, mostly in the 20,000–40,000 ft altitude range, were made by U. S. Air Force, U. S. Navy, and British Royal Aircraft Established aircraft (Fig. 4.7). The cooperative program, substantially supported by NASA and FAA, determined the probabilities of turbulence encounters in relation to the characteristics of thunderstorm radar echoes. These data are a basis for FAA Advisory Circular 00–24, "Thunderstorms."

In 1973, Doppler radar offered a serious prospect for improved turbulence detection, and a second series of thunderstorm investigations was begun with concentration at lower altitudes. With support of the Federal Aviation Administration and Department of Defense participation, synchronous observations were obtained by aircraft, standard weather radar and Doppler radar, and real-time displays, such as the Plan Shear Indicator, were utilized. A graphic display programmed by NSSL to display fields of radial velocity variability and radar reflectivities simultaneously in real time indicates that turbulence will be better indicated by the combination of reflectivity with velocity.

In 1976 we began an investigation of turbulence and wind shear associated with thunderstorm gust fronts, the cold-air outflow from convective storms (Fig. 7.7). This project with substantial FAA support uses an instrumented F4C aircraft and the tall tower of KTVY, instrumented at six levels for measurements of wind, temperature, and relative humidity. Storm gust fronts have been implicated in several recent tragic crashes of

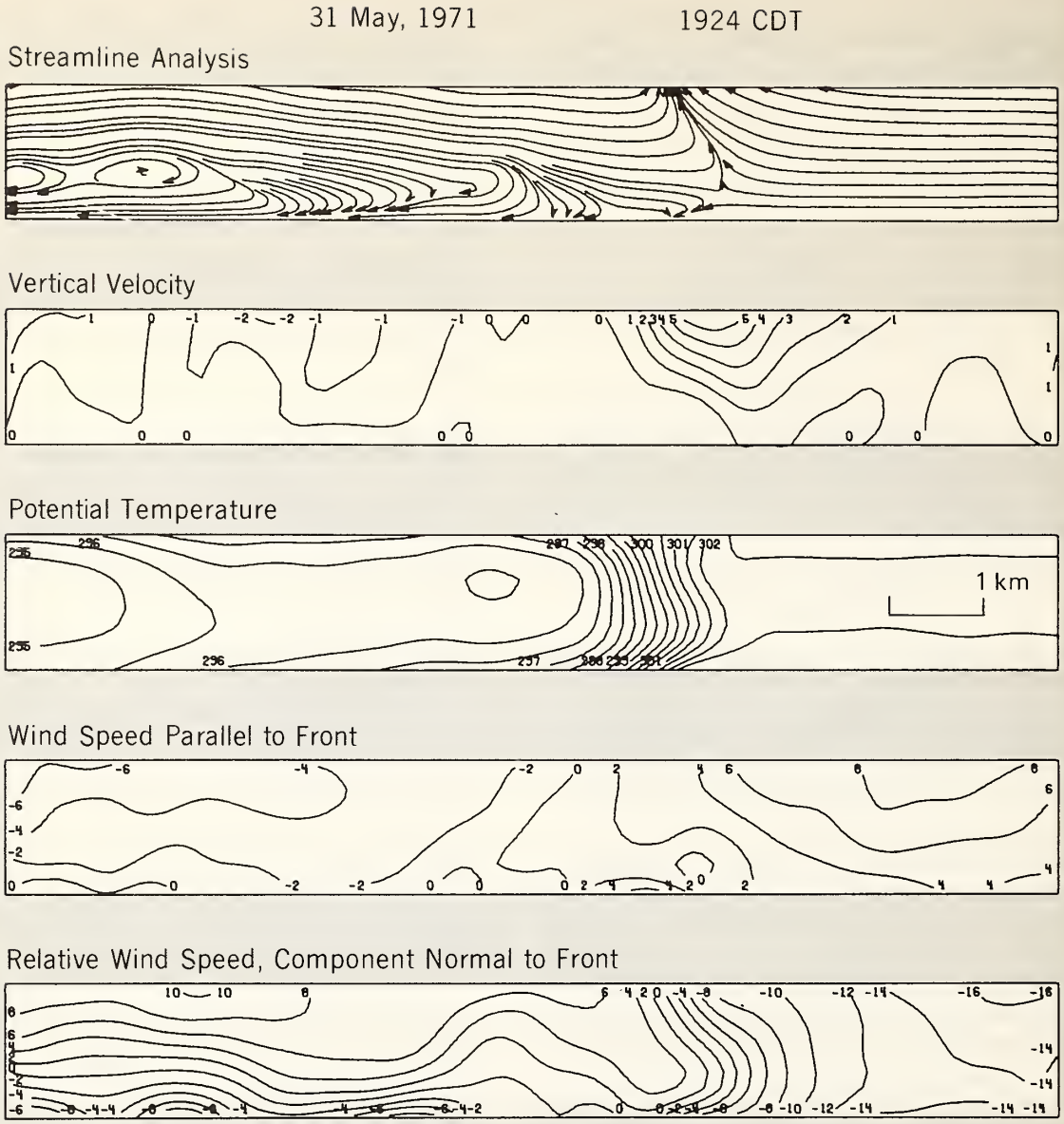
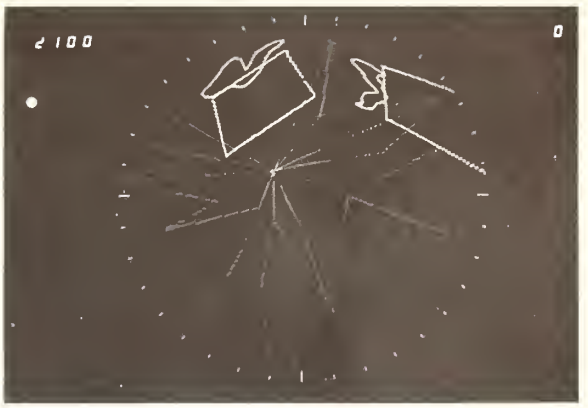


Figure 7.7 Streamline analysis and time-height sections of vertical velocity (m/s); potential temperature (°K); and wind speed components parallel and perpendicular to a gust front recorded by radar and by instruments on the tower of KTVY Television, Oklahoma City.

commerical aircraft. Aims of this project, managed during 1976 by R. Craig Goff, are to help optimize flight near aircraft terminals during gust-front conditions, and to determine how instruments should be deployed to provide cost effective criteria for runway selection, airport closing, and guidance to pilots by flight service station personnel and aircraft controllers.

In a related study of aviation hazards an RB–57F reconnaissance aircraft has overflown 29 tornadoes or tornado-producing thunderstorms. But comparison of photographs thus obtained with photographs of nonsevere thunderstorms has yielded no visual clue to differentiate severe and nonsevere storms. Radar is still the most valuable tool for determining thunderstorm characteristics.

Figure 7.8 a) Echo contours derived from NSSL's WSR–57 radar and shown on a remote display, 2045 CST, 6 June 1975. Maximum range is 200 km.



b) Contours of the intense echoing centers and extrapolated storm motion for one hour beginning at 2100 CST, 6 June 1975.

7.9 Display of Radar Data at Sites Remote from the Console

Effective, inexpensive display of weather radar data at all the sites where the data is required has been an elusive goal of meteorologists and radar engineers. The alternative to remote display is more radars, an expensive and thoroughly impractical solution because of mutual radio interference. But NSSL chief engineer Dale Sirmans has mated a graphic display terminal to the NWS WSR–57 radar and to other radars, and David Zittel has prepared computer programs to display calculated properties of the radar data, such as echo positions extrapolated 30 minutes hence, and to display the zones where there is a near-term danger to aircraft. The graphics terminal is a continuously refreshed remote display of radar echo intensity contours.

Storm motion is determined mathematically from the position of echo centers at different times. New positions are predicted along with prediction error estimates based on analysis of recent echo behavior. Storm area and shape characteristics are derived by outlining predetermined intensity thresholds and matching the contours with a Fourier analysis. It has been shown that the first nine harmonics represent storm shapes with sufficient accuracy.

Mr. Zittel has determined that storms of moderate or greater intensity over areas of 100 to 1000 km² are well treated with this system. Figure 7.8 shows photographs of the remote display with (a) storm echo contours, and (b) contours of the intense centers with expected storm movement for a 1 h period starting 15 min later than (a). FAA is considering the results of tests conducted at several Flight Service Stations with a view toward procuring several dozen of these programmable bright displays for use throughout the country.

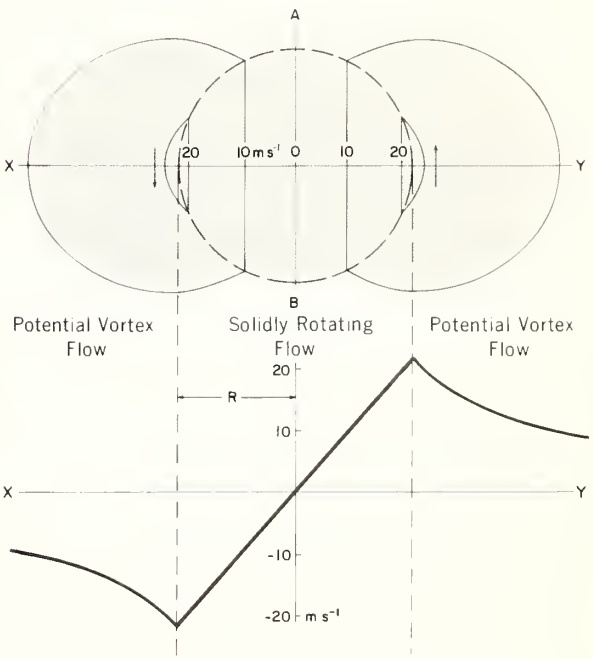


Figure 7.9 Single-Doppler radar signature of a horizontal stationary idealized vortex (upper) and velocity profile along the axis XY (lower).

7.10 Severe Storm and Tornado Identification with Doppler Radar

Medium-scale rotating wind systems (mesocyclones) associated with severe thunderstorms and tornadoes can be identified from single Doppler radar data by applying objective criteria to cyclonic vortex signatures (Fig. 7.9). The signatures are easily recognized from quasi-horizontal velocity fields (Fig. 4.6) and maintain good time and height continuity. Furthermore, Doppler radar measurements

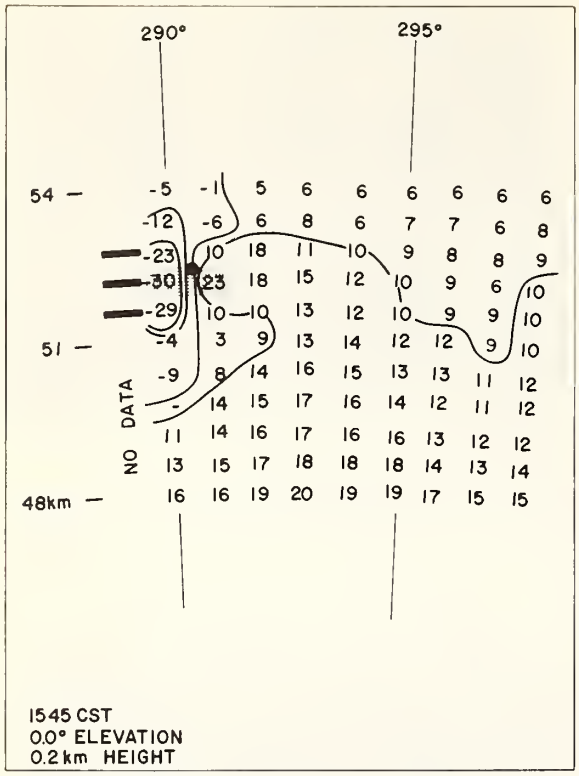


Figure 7.10 Union City tornado vortex signature near ground within a field of radar mean velocities (m/s) detected with NSSL's Doppler radar at Norman. Velocities away from radar are positive, toward radar are negative. The dark dot indicates the tornado position at the ground. Dark rectangles indicate the relative size of the sampled volume.

in the Union City, Oklahoma, tornadic storm of May 24, 1973, led to the discovery of a unique tornado signature. The tornado signature appears in the mean Doppler velocity field as a pair of anomalously high velocity values of opposite sign just one beamwidth apart (Fig. 7.10). Observations of the tornado signature by Rodger Brown, Don Burgess, and Leslie Lemon are supported by a theoretical model formulated by Dusan Zrnic. As the tornado becomes small relative to the beamwidth (e.g., with increasing range), the signature's amplitude decreases until it is no longer distinguishable from wind variations in the parent wind system.

Single-Doppler data collected at NSSL since 1971 reveal 37 mesocyclone signatures within 160 km of NSSL for which sizes and relationships to severe weather have been tabulated. The average mesocyclone has a peak rotational velocity of 22 m s^{-1}, a horizontal diameter of 5.7 km, and a vertical extent greater for those mesocyclones which produce severe or "maxi" tornadoes.

At least 23 of the 37 single-Doppler mesocyclone signatures are associated with reported tornadoes. Of the remaining 14 signatures, 12 are related to damaging wind or hail. At no time during data collection has a verified tornado occurred unless preceded by a mesocyclone signature. The NSSL data show an average lead time of 36 min before tornado occurrence.

Doppler data has provided much new information about mesocyclone and tornado evolution. Both mesocyclones and tornadoes form at storm midlevels and develop upward and downward with time until they extend through the storm's lower 10 km. The tornado signature appears to dissipate from storm top downward, so that by the time the tornado decays the signature has disappeared. Then the dying mesocyclone is also noted as a large-diameter, weak, low-level circulation embedded in the storm's precipitation core.

The findings summarized above provide essential background to a project begun in 1976 and jointly staffed from NSSL and the NWS. This aims to develop specifications for a Doppler radar system that will bring to the NWS a marked improvement in the precision and timeliness of their forecasts and warnings. In this project, during first seasonal tests, the Doppler radar at NSSL Headquarters will be jointly staffed by NSSL and NWS forecasters and its indications evaluated for use in actual forecast operations in the Oklahoma City area. Kenneth Wilk is Manager of this project for NSSL.

8. The Future

The view we have of ongoing work in NSSL provides a basis for projection of an appropriate future program. Needs press now in three areas of study and observation: (1) research including storm modeling into the dynamical processes of storms; (2) observation of relationships among the fields of wind, precipation, and electricity; and (3) a sustained commitment of resources for operational support of research with three Doppler radars.

Regarding meteorology research, our full time staff in this area number only 11 at the end of the 1976 transition quarter. It should be recognized that the unique facilities which underlie many of NSSL's discoveries require a disproportionate share of present staff for their support. NSSL should be authorized to engage additional meteorologists, including several at the Ph.D. level, and be provided funds to pay their salaries and supporting staffs.

The technology now available provides unprecedented capability for precision and detail in observations of wind and water distributions and electric charge centers, as they develop together. Such observations are crucial to knowledge of the associated interacting processes. Many important basic and applied problems, including questions critical to resolution of precipitation modification controversies, await solution with the aid of such observations. Indeed, we now stand at the very portal of the thunderstorm's main machinery room, so to speak.

In Edward T. Pierce, a 1976 arrival at NSSL, we have the expertise required to direct deployment and use of electrical sensor. William Taylor, expert at use of directional sensors for locating centers of electrical activity, will be participating in NSSL's 1977 spring program, and is expected to join the staff permanently early in 1978. David Rust, expert at field investigation of electrical discharge characteristics, is expected to join the staff permanently in mid-1977. The Laboratory requires funds and personnel to support observations on storm electricity complementary to other observations, while maintaining other priority work and developing meteorology research staff.

Use of the Doppler radar of the Illinois State Water Survey at NSSL implies a substantial and well justified burden for support. We provide for transportation and operation of their 10-cm Doppler radar and we should support ISWS participation with the Atmospheric Dynamics groups at the University of Illinois and University of Chicago in analysis and interpretation of the data. Furthermore, there must be additional strength in NSSL's computing facility for the great scope and complexity of 3-Doppler data analysis.

In order to accommodate this expansion of the program and to provide space not available even now for guest workers, it is proposed that 300 square meters of office space be constructed as a permanent addition to our building, with amortization costs incorporated into our present lease with the University of Oklahoma.

The increased staff and funds contemplated above amount to approximately one-third of the present program and should bring us to a size near the optimum, given the present organization and administrative arrangements in the meteorological community.

Since search for new resources entails considerable unproductive administrative effort, we emphasize wise use of the existing recurrent funding base and maintenance and development of quality, rather than quantity. Research progress seems realizable also by more effective coordination of talents in the meteorology community which are already supported within the federal budget.

9. Acknowledgments

Most of NSSL staff listed in Table 3.1 were active participants in preparation of this report. The NSSL has been fortunate in having persons so competent and dedicated on its staff since its founding, and the author is fortunate to have been their companion in zealous search.

Appendix A

Biographies of NSSL Professional Staff—1976

As in other organizations of its size, there is a large variety of tasks in the national Severe Storms Laboratory. This variety extends among the professional staff whose relevant experience is presented as a documentary example of the special kinds of expertise required in research activities.

In an organization devoted primarily to research, achievement tends often to be measured by quantity of publications. The reader is cautioned that often this is an incomplete and sometimes inaccurate measure. Indeed, those at NSSL whose work finds most expression through publications are necessarily most supported by many others—computer specialists, engineers, and managers, whose competence is equally essential to effectiveness of the organization, and to the printed materials which communicate our findings.

In addition to those with professional backgrounds, NSSL's productivity rests essentially on the enthusiastic good work of technicians, administratiors, and clerical personnel. And without NSSL's several well-qualified secretaries, devoted as they are to good work in the public interest, our whole organization would tumble down.

Ronnie L. Alberty
Head of Meteorology Research Group

Dr. Alberty joined the National Severe Storms Laboratory as leader of its Modeling Project in 1972. In 1974, he was selected to head the Meteorological Research Group, which includes more than one third of NSSL's scientists.

From 1967 through 1972, Dr. Alberty was a professor in the Department of Meteorology, U. S. Naval Postgraduate School, Monterey, California. There he taught graduate courses in meteorological thermodynamics, dynamics, upper atmospheric physics, and heat-transfer processes, and supervised thesis projects involving mesoscale analysis, severe storm morphology, and numerical modeling. His teaching effectiveness was recognized by the Excellence in Teaching Award for 1972, awarded for high esteem of both colleagues and students.

Dr. Alberty attended Sarcoxie Public Schools, Sarcoxie, Missouri, where he received the Mathematics Award, American Legion Award, various athletic awards, and a University of Missouri Curator's Award. He was a radar technician during four years active duty in the U. S. Air Force, before entering college and graduate level education. At the University of Missouri he worked in such varied areas as solar radiometry and severe storm dynamics.

Educational Background

Graduated, Joplin Junior College, Joplin, Missouri, 1961

Physics, B.S. (1963): Meteorology, M.S. (1965); Ph.D. (1967): University of Missouri

Professional Affiliations

American Meteorological Society
Phi Theta Kappa
Sigma Xi
Adjunct Associate Prof., Meteorology Dept., University of Oklahoma

Publications and Reports

An economical solar radiometer. Master's Thesis, University of Missouri, Columbia, 50 pp., 1965.

Dynamic pressure effects in organized convection. Ph.D. Dissertation, University of Missouri, Columbia, 76 pp., 1967.

An analysis of a severe local storm using isentropic trajectories. Naval Postgraduate School, Tech. Report NPS–51A19081A, 135 pp., 1969 (with K. L. Van Sickle).

A proposed mechanism for cumulonimbus persistence in the presence of strong vertical shear. *Monthly Weather Review*, **97**(8), 590–596, 1969.

An economical net solar flux radiometer. Conf. on Atmospheric Radiation of the Amer. Meteor. Soc., Ft. Collins, Colo., August, 1972 (with G. L. Darkow).

Tornado-parent storm relationship deduced from a dual-Doppler radar analysis. *Geophysical Research Letters*, **3**, 721–723, 1976 (with P. S. Ray, C. E. Hane, R. P. Davies-Jones).

Jack T. Andrews
Administrative Officer

Mr. Andrews joined the NSSL staff in January 1973. His major responsibilities are for administration of budget and personnel, and he also oversees important aspects of contracts, grants, and procurement of equipment, supplies and services.

Though born and raised around Washington, D.C., Mr. Andrews first entered civilian government service in 1943 at McClellan Army Depot (now McClellan Air Force Base), Sacramento, California. In September 1944 he joined the Navy and spent his military career as a ground school flight instructor. After his discharge at Corpus Christi, Texas, he remained awhile in similar Navy employment as a civilian. He later held increasingly responsible jobs in both Federal and private sectors, working in Washington, D. C., New York City, Florida, and California. In Santa Barbara, California, he and his wife established and managed a retail business (coffee, teas, spices, and gourmet cook items). When business success was established, he returned to Federal Service at Port Hueneme, California. He transferred to the Personnel Office of Department of Commerce, ESSA (now NOAA, ERL) at Boulder, Colorado in 1968, and remained there until reassignment to NSSL.

Educational Background

Mr. Andrews's primary education was completed in the Washington, D. C., school system through the GED examination with scores comparable to university sophomore level. He completed requirements for Commercial Pilot License in 1950 at Pensacola, Florida. He has also completed a host of technical and business courses and is currently enrolled in night classes on business management at a local college.

Edward A. Brandes
Meteorologist

Mr. Brandes has been employed at the National Severe Storms Laboratory since August 1971. His efforts have been primarily directed towards estimation of precipitation by radar and investigation of severe storm kinematic properties with Doppler radar. Rainfall studies have led to development of techniques to optimize radar estimates by incorporating rain gage observations. The technique is currently being tested by the Tulsa River Forecast Center and the Office of Hydrology, National Weather Service.

Prior to joining NOAA, Mr. Brandes attended New York University and worked as a research assistant on the "East Coast Snow Prediction Project." Accomplishments included the development of regression equations utilizing both observed and forecast meteorological variables to predict precipitation depth. Other studies determined the climatology of east coast heavy snows and a search was conducted for necessary synoptic conditions.

From 1964 to 1968 Mr. Brandes served as weather forecaster and chief weather forecaster in the U.S. Air Force. Duty stations included Shaw AFB, South Carolina; Thule AB, Greenland; and England AFB, Louisiana.

While at NSSL, Mr. Brandes has (a) developed techniques for improving processing of weather

radar data; (b) developed techniques to optimize radar rainfall estimates; and (c) conducted studies utilizing dual-Doppler radar measurements to describe severe thunderstorm life cycle and severe weather production.

Educational Background

Mechanical Engineering, B.S. (1964), Newark College of Engineering
Meteorology, M.S. (1970), New York University.

Professional Affiliations

American Meteorological Society

Publications and Reports

A search for necessary conditions for heavy snow on the east coast. *J. Appl. Meteor.*, **10**, 397–409, 1971 (with J. Spar).

The use of digital radar data in severe storm detection and prediction. *Preprints,* 15th Radar Conf., Champaign-Urbana, Ill., Amer. Meteor. Soc., October 11–12, 45–48, 1972.

The variation of Oklahoma spring rains as revealed by radar. *Preprints,* Eighth Conf. on Severe Local Storms, Denver, Colo., Amer. Meteor. Soc., October 15–17, 146–148, 1973.

Radar rainfall pattern optimizing technique. NOAA Tech. Memo. ERL NSSL–67, Norman, Okla., 16 pp., 1974.

Severe thunderstorm flow characteristics revealed by dual-Doppler observations: 6 June 1974. *Preprints,* Ninth Conf. on Severe Local Storms, Norman, Okla., Amer. Meteor. Soc., October 21–23, 85–90, 1975.

Optimizing rainfall estimates with the aid of radar. *J. Appl. Meteor.*, **14**(7), 1339–1345, 1975.

Convective rainfall estimation by radar: experimental results and proposed operational analysis technique. *Preprints,* Conf. on Hydro-Meteorology, Ft. Worth, Tex., Amer. Meteor. Soc., April 20–22, 54–59, 1976 (with D. Sirmans).

Rodger A. Brown
Meteorologist

In 1970, after having worked briefly at NOAA's Wave Propagation Laboratory, Boulder, Colorado, Mr. Brown joined NSSL. He has been using the NSSL Doppler radars with other meteorological sensors to explore the structure and evolution of tornado-producing thunderstorms.

Before joining NOAA, Mr. Brown was a Research Meteorologist at the Cornell Aeronautical Laboratory, Buffalo, New York. There he studied mesoscale features of lake-effect convective snowstorms and applied Doppler radar to investigate thunderstorm characteristics.

From 1960 to 1965, Mr. Brown was employed with the Satellite and Mesometeorology Research Project, University of Chicago. There he developed cloud photogrammetric procedures and applied them with mesoscale analysis techniques to the study of convective storms.

From 1955 through 1959, Mr. Brown held several short term meteorological positions as part of Antioch College's study-plus-work educational program. He was a weather observer at the Mount Washington Observatory in New Hampshire and a weather observer and Research Assistant at the Blue Hill Meteorological Observatory, Harvard University, Milton, Massachusetts. Following a tour as Scientific Aide with the Severe Local Storms Research Unit, U. S. Weather Bureau, Washington, D.C., he spent 13 months at Little America V, Antarctica, as a Weather Bureau observer and rawinsonde operator.

Mr. Brown's primary contribution to the advancement of meteorological knowledge has been an improved understanding of the structure and evolution of tornadic storms. He is co-discoverer of the Doppler radar signature for a tornado.

Educational Background

Earth Science, B.S. (1960), Antioch College, Yellow Springs, Ohio
Geophysical Sciences (Meteorology), M.S. (1962), University of Chicago
Graduate studies, University of Oklahoma

Professional Affiliations

American Meteorological Society
American Geophysical Union
Canadian Meteorological Society
Royal Meteorological Society
Society of the Sigma Xi

Publications and Reports

Nocturnal rainbow. *Weather,* **14**, 36, 1959.

Report on the Chicago Tornado of March 4, 1961. Univ. of Chicago, Dept. of Geophys. Sci., Mesometeor. Project Research Paper No. 1, 13 pp., 1961 (with T. Fujita).

On the mesometeorological field studies near Flagstaff, Arizona. *J. Appl. Meteor.*, **1**, 26–42, 1962 (with T. Fujita and K. A. Styber).

On the determination of the exchange coefficients in convective clouds. Univ. of Chicago, Dept. of Geophys. Sci., SMRP Research Paper No. 41, 7 pp., 1965.

A study of factors contributing to dissipation of energy in a developing cumulonimbus. Univ. of Chicago, Dept. of Geophys. Sci., SMRP Research Paper No. 42, 65 pp., 1965 (with T. Fujita).

On the 'thunderstorm-high controversy.' Univ. of Chicago, Dept. of Geophys. Sci., SMRP Research Paper No. 46, 26 pp., 1965.

The land and sea breeze: an annotated bibliography. Article F on Final Report Contract No. AF 19(604)–7259, Univ. of Chicago, Dept. of Geophys. Sci., 61 pp., 1965 (with G. L. Baralt).

Occurrence of supernumerary fogbows at subfreezing temperatures. *Mon. Weather Rev.*, **94**, 47–48, 1966.

On the determination of exchange coefficients: Part II. Rotating and non-rotating convective currents. Univ. of Chicago, Dept. of Geophys. Sci., SMRP Research Paper No. 54, 30 pp., 1966.

Three-dimensional growth characteristics of an orographic thunderstorm system. Univ. of Chicago, Dept. of Geophys. Sci., SMRP Research Paper No. 61, 45 pp., 1966.

Comments on 'A note on the square cloud.' *J. Atmos. Sci.*, **24**, 305–307, 1967.

Mass and available energy in growing convective clouds. *J. Atmos. Sci.*, **24**, 308–311, 1967.

A study of lake effect snowstorms. CAL Report No. VS–2355–P–1, Buffalo, Cornell Aeronautical Lab., 55 pp., 1967 (with G. E. McVehil, J. E. Juisto and R. L. Peace, Jr.).

A study of lake effect snowstorms. CAL Report No. VS–2355–P–2, Buffalo, Cornell Aeronautical Lab., 83 pp., 1967 (with G. E. McVehil, J. E. Juisto and R. L. Peace, Jr.).

A study of hydrologic and energy budgets of Lake Erie with emphasis on evaporation measurement. Buffalo, Cornell Aeronautical Lab., CAL Report No. RM–2432–0–3, 38 pp., 1967 (with R. L. Peace, Jr. and G. E. McVehil).

Mesoanalysis of convective storms utilizing observations from two Doppler radars. *Proceedings*, 13th Radar Meteor. Conf., Boston, Amer. Meteor. Soc., 188–191, 1968 (with R. L. Peace, Jr.).

Comparison of single and double Doppler radar velocity measurements in convective storms. *Proceedings*, 13th Radar Meteor. Conf., Boston, Amer. Meteor. Soc., 464–473, 1968 (with R. L. Peace, Jr.).

Final report of environmental support panel, U. S. Navy VLF special communications study. Buffalo, Cornell Aeronautical Lab., CAL Report No. CM–2520–B–1, 85 pp., 1968 (with W. H. Keith).

Investigation of severe storms utilizing Doppler radar. Buffalo, Cornell Aeronautical Lab., CAL Report No. VS–2428–P–2, 39 pp., 1968 (with R. L. Peace, Jr. and C. C. Easterbrook).

Horizontal motion field observations with a single pulse Doppler radar. *J. Atmos. Sci.*, **26**, 1096–1103, 1969 (with R. L. Peace, Jr. and H. G. Camnitz).

New England tornadoes: Climatological survey from first settlement through 1968. *Proceedings*, 6th Severe Local Storms Conf., Boston, Amer. Meteor. Soc., 238–243, 1969.

Characteristics of forest vegetation analogs. Buffalo, Cornell Aeronautical Lab., CAL Report No. VT–2408–P–1, 98 pp., 1969 (with G. E. McVehil, R. L. Peace, Jr., and R. W. Coakley).

Preliminary Doppler velocity measurements in a developing radar hook echo. *Bull. Amer. Meteor. Soc.*, **52**, 1186–1188, 1971 (with W. C. Bumgarner, K. C. Crawford and D. Sirmans).

Doppler radar evidence of severe storm high-reflectivity cores acting as obstacles to airflow. *Preprints*, 15th Radar Meteor. Conf., Boston, Amer. Meteor. Soc., 16–21, 1972 (with K. C. Crawford).

Doppler velocity measurements in an approaching squall line. *Preprints*, 15th Radar Meteor. Conf., Boston, Amer. Meteor. Soc., 27–34, 1972 (with K. C. Crawford).

The structure of a severe right-moving thunderstorm: New single Doppler radar evidence. *Preprints*, 8th Conf. on Severe Local Storms, Boston, Amer. Meteor. Soc., 40–43, 1973 (with D. W. Burgess).

Twin tornado cyclones within a severe thunderstorm: single Doppler radar observations. *Weatherwise*, **26**, 63–69 and 71, 1973 (with D. W. Burgess and K. C. Crawford).

Applications of conventional and Doppler radar measurements in severe storm research. *Preprints*, 3rd Symposium on Meteor. Observations and Instrumentation, Boston, Amer. Meteor. Soc., 165–174, 1975 (with K. E. Wilk).

Tornado characteristics revealed by Doppler radar. *Geophys. Res. Lett.*, **2**, 183–184, 1975 (with D. W. Burgess and L. R. Lemon).

Evolution of a tornado signature and parent circulation as revealed by single Doppler radar. *Preprints*, 16th Radar Meteor. Conf., Boston, Amer. Meteor. Soc., 99–106, 1975 (with D. W. Burgess and L. R. Lemon).

Tornado production and storm sustenance. *Preprints*, 9th Conf. on Severe Local Storms, Boston, Amer. Meteor. Soc., 100–104, 1975 (L. R. Lemon and D. W. Burgess).

NSSL dual-Doppler radar measurements in tornadic storms: a preview. *Bull. Amer. Meteor. Soc.*, **56**, 524–526, 1975 (D. W. Burgess, J. K. Carter, L. R. Lemon and D. Sirmans).

Single Doppler radar vortex recognition: Part II. Tornadic vortex signature. *Preprints*, 17th Conf. on Radar Meteor., Boston, Amer. Meteor. Soc., 104–109, 1976 (with L. R. Lemon).

Tornado and mesocyclone detection with single Doppler radar. *Proceedings*, Symposium on Tornadoes, Texas Tech University, Lubbock, Tex., 1976 (with D. W. Burgess).

William C. Bumgarner
Computer Specialist

Since 1970 Mr. Bumgarner has been in the Computing and Data Processing Group at the NSSL. His contributions to the NSSL program are fundamental in the area of Doppler radar processing and systems programming. He designed and implemented radar data processing and archival schemes, and has provided systems support for all computer systems used by the Laboratory.

From 1967 to 1970, Mr. Bumgarner was a systems analyst in the Forecast Techniques section at this Laboratory. From 1965 to 1967, he was employed by the University of Oklahoma as a scientific programmer, and was a graduate teaching assistant in the OU Physics Department. While an undergraduate from 1961 to 1964 he worked for the OU Mathematics Department as an instructor in the computer laboratory.

Educational Background

Mathematics, B.S. (1964), Physics, M.S. (1968), University of Oklahoma

Graduate work in meteorology and computer science (1969 to 1976), University of Oklahoma

Professional Affiliations

Association of Computing Machinery

Publications and Reports

Model of precipitation and vertical air currents. NOAA Tech. Memo. ERL NSSL–54, Norman, Oklahoma, 93 pp., 1971 (with E. Kessler).

Dual-Doppler observation of a tornadic storm. *Preprints*, 16th Radar Meteor. Conf., Houston, Texas, April, 115–120, 1976 (with P. S. Ray, R. J. Doviak, G. B. Walker, D. Sirmans, and J. Carter).

Estimation of spectral density mean and variance by covariance argument techniques. *Preprints*, 16th Radar Meteor. Conf., Houston, Texas, April, 6–13, 1976 (with D. Sirmans).

Receiver chain and signal processing effects on the Doppler spectrum. *Preprints*, 16th Radar Meteor. Conf., Houston, Texas, April, 163–168, 1976 (with D. S. Zrnic).

Numerical comparison of five mean frequency estimators. *J. Appl. Meteor.*, **14**(6), 991–1003, 1975 (with D. Sirmans).

Dual-Doppler observation of a tornadic storm. *J. Appl. Meteor.*, **14**(8), 1521–1530, 1975 (with P. S. Ray, R. J. Doviak, G. B. Walker, D. Sirmans, and J. Carter).

Extension of maximum unambiguous Doppler velocity by use of two sampling rates. *Preprints*, 17th Radar Meteor. Conf., Seattle, Washington, October, 23–28, 1976 (with D. Sirmans and D. S. Zrnic).

Donald W. Burgess
Meteorologist

Since joining NSSL in September 1973, Mr. Burgess has worked with others to synthesize a diagnostic thunderstorm model from observations of external storm processes and Doppler radar indications of internal storm flows. He has also accumulated several years Doppler data to reveal statistical relationships between Doppler observed velocity fields and tornadic or other damaging windstorms.

From 1970 to 1973, Mr. Burgess was a part time research assistant in the Doppler radar project while attending Oklahoma University, and he helped formulate NSSL Doppler data reduction and analysis techniques.

Mr. Burgess' most important contribution has been toward discovery and documentation of a region of high wind shear within tornadic thunderstorms: the Tornadic Vortex Signature (TVS). The TVS has, in several cases, preceded tornado formation by tens of minutes. There is the possibility that this discovery will provide the scientific basis for improved tornado warnings. This contribution resulted in a NOAA Special Achievement Award (February 1976).

Educational Background

Meteorology, B.S. (1971), M.A. (1974), University of Oklahoma, Norman, Oklahoma

Mr. Burgess also attended Central State College, Edmond, Oklahoma (1966)

Professional Affiliations

American Meteorological Society
Sigma Tau (Professional Engineering Fraternity)

Publications and Reports

Twin tornado cyclones within a severe thunderstorm: single Doppler radar observations. *Weatherwise*, **26**(2), 63–69 and 71, 1973 (with R. A. Brown, and K. C. Crawford).

The structure of a severe right-moving thunderstorm: new single Doppler radar evidence. *Preprints*, Eighth Conf. on Severe Local Storms, Amer. Meteor. Soc., Boston, 40–43, 1973 (with R. A. Brown).

Observations of Doppler isotach and reflectivity structure observed within a tornadic storm. *J. Rech. Atmos.*, **VIII**, 1–2 and 235–243, 1974 (with R. J. Doviak, L. R. Lemon, and D. Sirmans).

Real-time Doppler isotach and reflectivity signature of a tornado cyclone. *Bull. Amer. Meteor. Soc.*, **55**(9), 1126–1127, 1974.

Study of a severe right-moving thunderstorm utilizing new single Doppler evidence. Masters Thesis, University of Oklahoma, Norman, Okla., 77 pp., 1974.

NSSL dual-Doppler radar measurements in tornadic storms: a preview. *Bull. Amer. Meteor. Soc.*, **56**(5), 524–526, 1975 (with R. A. Brown, J. Carter, L. R. Lemon, and D. Sirmans).

Evolution of a tornado signature and parent circulation as revealed by single Doppler radar. *Preprints*, 16th Radar Meteor. Conf., Amer. Meteor. Soc., Boston, 99–106, 1975 (with L. R. Lemon and R. A. Brown).

Tornado characteristic revealed by Doppler radar. *Geophys. Res. Lett.*, **2**(5), 183–184, 1975 (with L. R. Lemon and R. A. Brown).

Tornado production and storm sustenance. *Preprints*, Ninth Conf. on Severe Local Storms, Amer. Meteor. Soc., Boston, 100–104, 1975 (with L. R. Lemon and R. A. Brown).

Analysis of the June 4, 1973 Norman tornadic storm. *Preprints*, Ninth Conf. on Severe Local Storms, Amer. Meteor. Soc., Boston, 384–388, 1975 (with R. P. Davies-Jones and L. R. Lemon).

Single Doppler radar vortex recognition: Part I. Mesocyclone signature. *Preprints*, 17th Radar Meteor. Conf., 97–103, 1976.

Tornado and mesocyclone detection with single Doppler radar. *Proceedings*, Symposium on Tornadoes, Texas Tech University, 1976 (with R. A. Brown).

Tornado characteristics revealed by a pulse Doppler radar. *Preprints*, 17th Radar Meteor. Conf., 110–117, 1976 (with D. S. Zrnic, R. J. Doviak and D. Sirmans).

Stephen D. Burk
NRC Associate

Since July 1975, Dr. Burk has been a National Research Council Resident Research Associate at the National Severe Storms Laboratory where he has developed a higher order turbulence closure model for studies of the planetary boundary layer. With this model he has investigated the temporal behavior of moisture stratification within the diurnally varying PBL.

Dr. Burk has a broad background in physics and the study of planetary atmospheres. In 1967, he received an A.B. in physics from the University of California at Berkeley, with a minor in mathematics. From September 1967 to January 1969 he worked as a teaching assistant in the Dept. of Physics at the University of Arizona. As a research assistant at the Lunar and Planetary Laboratory from July 1968 to June 1970, Dr. Burk worked with the late Dr. Gerard P. Kuiper in spectroscopic investigations of planetary atmospheres.

In January 1970, Dr. Burk received an M.S. degree in physics, and entered the Dept. of Atmospheric Sciences at the University of Arizona.

Upon being awarded a NASA Traineeship, he worked with Dr. Wayne McGovern in study of the upper atmosphere of Jupiter, and investigations of planetary atmospheric evolution.

Dr. Burk's Ph.D. dissertation dealt with the nature of the winds near the Martian polar caps. A two-dimensional numerical model was developed to study the response of the Martian atmosphere to non-uniform diurnally varying surface heating in the highly baroclinic region near the polar cap periphery. Particular attention was paid to the radiative transfer properties of the CO_2 dominated atmosphere, and to the dust lifting potential of these polar winds in light of both ground based and Mariner spacecraft evidence of frequent dust storm activity near the caps.

Educational Background

Physics, A.B. (1967), University of California at Berkeley

Physics, M.S. (1970), Atmospheric Physics, Ph.D. (1975), The University of Arizona, Tucson

Professional Affiliations

American Meteorological Society

Publications and Reports

Upper atmospheric thermal structure of Jupiter with convective heat transfer. *J. Atmos. Sci.*, **29**, 179–189, 1972 (with W. McGovern).

Reflection spectra, 2.5–7 mm, of some solids of planetary interest. *Communications of the Lunar and Planetary Laboratory*, No. 185, Pt. 1, 8–20, 1973 (with V. Fink).

Numerical modeling of the diurnal winds near the Martian polar caps. Ph.D. Dissertation, The University of Arizona, 135 pp., 1975.

Diurnal winds near the Martian polar caps. *J. Atmos. Sci.*, **33**, 923–939, 1976.

John K. Carter

Electronics Engineer

Mr. Carter joined the Advanced Techniques Group at NSSL in February 1966. Previously he spent six years with the Federal Aviation Administration (FFA) Aeronautical Center, Will Rogers Field, Oklahoma City, in surveillance radar and display systems.

Mr. Carter's contributions have been fundamental with respect to specification, design, and documentation of the meteorologically instrumented KTVY tower data acquisition system, and design, development, and commissioning of NSSL's second Doppler radar system at Cimarron Field near Oklahoma City. He was also responsible with Mr. Dale Sirmans for documentation of the NSSL X-Band Doppler radar that figured prominently in our early Doppler research.

Educational Background

Mathematics-Physics, B.S. (1966), Central State University, Edmond, Oklahoma

Electrical Engineering Graduate Studies, University of Oklahoma

Professional Affiliations

Instrument Society of America—senior member

Publications and Reports

Engineering report on the pulse Doppler X-Band radar at the National Severe Storms Laboratory. ESSA Tech. Circ. No. 8, National Severe Storms Laboratory, Norman, Oklahoma, 26 pp., 1968 (with D. Sirmans).

Detection and presentation of severe thunderstorms by airborne and ground-based radars: A comparative study. NOAA Tech. Memo. ERL NSSL–43, 1969 (with K. E. Wilk and J. T. Dooley).

The meteorologically instrumented WKY–TV tower facility. NOAA Tech. Memo. ERL NSSL–50, 18 pp., 1970.

Dual-Doppler observation of a tornadic storm. *J. Appl. Meteor.*, **14** (8), 1521-1530, 1975 (with P. S. Ray, G. B. Walker, R. J. Doviak, and D. Sirmans).

Robert P. Davies-Jones

Geophysicist

Since September 1970, Dr. Davies-Jones has been a geophysicist with the National Severe Storms Laboratory, NOAA. Currently he is team leader of the Vortex Dynamics Group and of the Tornado Intercept Project. His research topics include theoretical and observational investigations of tornadic flows, relationships of tornadoes to parent thunderstorms, improved short term tornado prediction, accurate estimation of tornado parameters and improved understanding of thunderstorm processes. This research utilizes meteorology, physics, mathematics, numerical modeling and computer programming. He also acts as a consultant on tornadoes to other government agencies, monitors NOAA grants, reviews proposals for funding agencies, and referees papers for science journals.

During 1969–1970, Dr. Davies-Jones held a postdoctoral position at the National Center for Atmospheric Research. He was a research assistant at the High Altitude Observatory and the University of Colorado from 1964 to 1969.

Educational Background

Physics, B.S. (hons.) (1964), Birmingham University, England
Astrogeophysics, Ph.D. (1969), University of Colorado

Professional Affiliations

American Meteorological Society
Adjunct Assistant Professor, Meteorology Department, University of Oklahoma

Publications and Reports

Problem studied during the thermal convection colloquium. NCAR Tech. Note 24, 525–550, 1967.

The linear theory of thermal convection in horizontal plane couette flow. Ph.D. Thesis, Univ. of Colorado, 216 pp. (also AFCRL–69–0382), 1969.

On large scale solar convection. *Sol. Phys.*, **12**, 3–22, (also AFCRL–69–0491, NCAR MS 69–151), 1970 (with P. A. Gilman).

Thermal convection in an infinite channel with no-slip sidewalls. *J. Fluid Mech.*, **44**, 695–704 (also NCAR MS 69–179), 1970.

Thermal convection in a horizontal plane couette flow. *J. Fluid Mech.*, **49**, 193–205, (also NCAR MS 69–144), 1970.

Convection in a rotating annulus uniformly heated from below. *J. Fluid Mech.*, **46**, 65–81 (also AFCRL–70–0229 and NCAR MS 70–42), 1971 (with P. A. Gilman).

Comments on "Some aspects of a severe right moving thunderstorm deduced from mesonetwork and rawinsonde observations." *J. Atmos. Sci.*, **28**, 652–653, 1971 (with N. B. Ward).

Numerical simulation of convective vortices. NOAA Tech. Memo. ERL NSSL–57, Norman, Okla., 27 pp. (also NCAR MS 71–199), 1971 (with G. T. Vickers).

The dependence of core radius on swirl ratio in a tornado simulator. *J. Atmos. Sci.*, **30**, 1427–1430, (nominated for ERL Outstanding Scientific Paper Award, 1974), 1973.

Characteristics of thunderstorm updraft soundings. *Proceedings*, Eighth Conf. on Severe Local Storms, Denver, Colo., October, 1–5, 1973 (with J. H. Henderson).

Correspondence (on psychological response to tornadoes). *Science*, **180** (4086), 545, 1973 (with J. Golden and J. Schaefer).

Discussion of measurements inside high speed thunderstorm updrafts. *J. Appl. Meteor.*, **13**, 710–717, 1974.

Tornadoes. Chapter 16, *Weather and Climate Modification*, Editor, W. N. Hess, John Wiley and Sons, New York, 842 pp., (nominated for ERL Outstanding Scientific Paper Award, 1975), 1974 (with E. Kessler).

Updraft properties deduced from rawinsondings. NOAA Tech. Memo. ERL NSSL–72, Norman, Okla., 117 pp., 1974 (with J. H. Henderson).

On the relation of electrical activity to tornadoes. *J. Geophys. Res.*, **80**, 1614–1616, 1975 (with J. H. Golden).

Photogrammetric wind speed analysis and damage interpretation of the Union City, Oklahoma tornado May 24, 1973. *Proceedings*, Second U. S. National Conf. on Wind Engineering Research, Ft. Collins, Colo., June 22–25, 1975 (with J. H. Golden).

Updraft properties deduced statistically from rawinsondings. *Pure and Appl. Geophys.*, **113**, 787–801, (special cloud dynamics issue), 1975 (with J. H. Henderson). Also in *Contributions to Current Research in Geophysics*, Vol. 2, Cloud Dynamics, Editor, H. R. Pruppacher, Birkhauser Verlag, Basel, Switzerland, 1976.

Analysis of the 4 June 1973 tornadic storm. *Proceedings*, Ninth Conf. on Severe Local Storms, Norman, Okla., October, 384–388, 1975 (with D. W. Burgess and L. R. Lemon).

Reply to Comments on "On the relation of electrical activity to tornadoes" by S. A. Colgate. *J. Geophys. Res.*, **80**, 4557, 1975 (with J. H. Golden).

Reply to Comments on "On the relation of electrical activity to tornadoes" by B. Vonnegut. *J. Geophys. Res.*, **80**, 4561, 1975 (with J. H. Golden).

Interpretation of surface marks and debris patterns from Union City tornado. Chapter 13, *The Union City Tornado of 24 May 1973*, Edited by R. A. Brown. NOAA Tech. Memo. ERL NSSL–78, 1976 (with D. Burgess, L. Lemon and D. Purcell).

Laboratory simulations of tornadoes. *Proceedings*, "A Symposium on Tornadoes; Assessment of Knowledge and Implications for Man," Texas Tech University, Lubbock, Texas, June 22–24, 1976.

J. T. Dooley

Meteorologist

Since January 1964, J. T. Dooley has been associated with the Severe Thunderstorm Detection and Identification Project at NSSL. The objective of this project is to improve techniques to detect, identify, and track hazardous weather events associated with severe thunderstorms.

Prior to 1964, Mr. Dooley was associated with the U. S. Weather Bureau's National Severe Storms Project in Kansas City, Missouri.

From 1957 to 1961, Mr. Dooley worked for the U. S. Weather Bureau in Kansas City, Missouri, both as an observer and research assistant.

Mr. Dooley's contributions to the Laboratory include 1) establishment of the NSSL subsynoptic scale network; 2) management of NSSL's mesonetwork data acquisition, processing, and archiving program from 1970 through 1974; 3) evaluation of the weather detection capabilities of the ASR–4 and ARSR–1D Air Traffic Control radars of the FAA; 4) development of a computer program for the evaluation of the NSSL Doppler's hardwired radial velocity and width estimators, namely, the Pulse Pair Processors; 5) development of certain operational and quality control procedures used in collection of WSR–57 digital and photographic data.

Educational Background

Mathematics, (1962), University of Missouri, Kansas City
Meteorology, (1960), Pennsylvania State University; (1962), University of Miami, Florida

Publications and Reports

A study of the comparative frequency of severe weather occurrences within 200 nmi radius of five midwestern cities. 11 pp., 1961.

Radar data acquisition techniques. ESSA Tech. Memo. NSSL–24, 122–130, 1965 (with C. Clark).

Weather detection by ARSR–1D, ASR–4, and WSR–57 radars: A comparative study. Tech. Memo. NSSL–1, 33 pp., 1965 (with K. Wilk and E. Kessler).

Doppler study of the motion of clear air targets. *Proceedings*, 12th Weather Radar Conf., October, 293–299, 1966 (with R. Lhermitte).

Toward a quantitative radar echo climatology. *Proceedings*, 13th Weather Radar Conf., August, 280–285, 1968 (with E. Kessler and K. Gray).

Detection and presentation of severe thunderstorms by airborne and ground-based radars: A comparative study. Tech. Memo. NSSL–43, 56 pp., 1969 (with J. Carter and K. Wilk).

The NSSL surface network and observations of hazardous wind gusts. ERL Tech. Memo. NSSL–55, 19 pp., 1971 (with NSSL Operations Staff).

Objectives and accomplishments of the NSSL 1975 spring program, Part II, Radar Quality Control Program. NOAA Tech. Memo. ERL NSSL–78, 47 pp., 1976 (with other NSSL Staff).

Charles A. Doswell III

Meteorologist

Mr. Doswell spent two summers at the Weather Bureau Airport Station at Madison, Wisconsin as a student trainee, where he trained in meteorologist duties—taking pilot balloon observations, operating the radar, participating in weather analysis and forecasting.

After graduation from University of Wisconsin, he was appointed Meteorologist with the National Severe Storms Forecast Center in Kansas City, Missouri (and was allowed to return to school each year on leave-without-pay status). Before entering military service, he spent one summer with the Public Service Unit at NSSFC and two summers with the Severe Local Storms Forecast Unit (SELS).

Toward the end of his service, from 1969 to 1972, he was assigned to the Atmospheric Modification Technical Area of the Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico. There he worked on numerical modeling techniques for fog. He was also a Special Instructor at New Mexico State Univ. and taught a course in Meteorology at White Sands.

Since leaving the Service he has been Research Assistant at the University of Oklahoma, applying variational analysis techniques to instrumented tower data.

Mr. Doswell's work at NSSL has been directed toward the analysis of surface data, with emphasis on band-pass filtering. In March 1976 he transferred to the Techniques Development Unit at the National Severe Storms Forecast Center, Kansas City, Missouri, where his work continues in cooperation with NSSL.

Educational Background

Meteorology, B.S. (1967), University of Wisconsin, Madison, Wisconsin

Meteorology, M.S. (1969), Ph.D. (1976), University of Oklahoma, Norman, Oklahoma

Professional Affiliations

Meteorological Society of Japan

University of Oklahoma Chapter of Chi Epsilon Pi (Meteorology Honorary Society)

Publications and Reports

On the interaction between the planetary boundary layer and large-scale vertical velocity. M.S. Thesis, University of Oklahoma, Norman, Okla., 1969.

A two-dimensional short-range forecast model. Atmos. Sciences Laboratory, White Sands Missile Range, ECOM–5443, 1972.

An iterative method for saturation adjustment. Atmos. Sciences Laboratory, White Sands Missile Range, ECOM–5444, 1972.

Rotating clouds at Norman, Oklahoma. Correspondence printed in *Bull. Amer. Meteor. Soc.*, **53**, 1180, 1972 (with S. A. Tegtmeier).

Field observations of the Union City tornado in Oklahoma. *Weatherwise*, **27**, 68–79, 1974 (with A. Moller, J. McGinley, S. Tegtmeier, and R. Zipser).

On the relationship of cirrus clouds to the jet stream. *Mon. Weather Rev.*, **104**, 105–106, 1976 (with J. T. Schaefer).

The use of filtered surface observations to reveal subsynoptic scale dynamics. Ph.D. Dissertation, University of Oklahoma, Norman, Okla., 1976.

Richard J. Doviak

Head of Advanced Techniques Group

Dr. Doviak joined the National Severe Storms Laboratory in October 1971 to lead the Doppler Radar Project in developing a meteorological Doppler radar system and to perform investigations leading to improved physical and numerical models of air motions within severe storm environments. Currently, as Chief of the Advanced Techniques Project, Dr. Doviak performs and directs studies of the interaction of meteorological targets with electromagnetic waves, and he works with staff of other NOAA elements and organizations to develop remote-sensing atmospheric probes. Dr. Doviak is also an Adjunct Associate Professor at the University of Oklahoma and has given courses and lectures to students.

Prior to Dr. Doviak's arrival at NSSL, he was Assistant Professor in the Department of Electrical Engineering at the University of Pennsylvania where

he performed research and lectured on topics related to electromagnetic theory and practice. From 1967 to 1971 he was Supervisor of the Academic Laboratories, and from 1968 to 1971 he led the development of a research facility for remote sensing at the University's Valley Forge Research Center. There he assembled a high power radar to investigate scattering from clear air. In a cooperative experiment with scientists from the Johns Hopkins Applied Physics Laboratory the existence of diffuse scattering regions within the clear atmosphere was established. Because of the uniqueness of the system they were able to resolve important sidelobe contributions that had hindered previous definition of atmospheric scattering structure.

From 1965 to 1967 Dr. Doviak was principal investigator to develop and study the first microwave spark chamber for detection of atomic particles. The program led to successful design of a chamber that had the isotropic properties of a bubble chamber but was triggerable so that selected atomic collisional events could be recorded.

Dr. Doviak has also been active in research related to antennas, propagation, and studies on the electromagnetic properties of materials.

Educational Background

Engineering (1952–1953), Fairleigh Dickinson College, Rutherford, New Jersey
Electrical Engineering, B.S. (1956), Rensselaer Polytechnic Institute, Troy, New York
Electrical Engineering, M.S. (1959), Ph.D. (1963), University of Pennsylvania

Professional Affiliations

American Meteorological Society
American Geophysical Union
American Association for the Advancement of Science
Institute of Electrical and Electronics Engineers
Tau Beta Pi (General engineering honor society)
Eta Kappa Nu (Electrical engineering society)
Sigma Xi (Research honor society)
Commissions C and F of the International Union of Radio Science
Adjunct Associate Professor (1972–present), University of Oklahoma.

Publications and Reports

A tristimulus computer. B.S.E.E. Thesis, Rensselaer Polytechnic Institute, 1956.

Evaluation of ferrite materials for possible application on the Princeton-Pennsylvania 3 BEV proton synchrotron. Moore School of Electrical Engineering, Report No. 58–05, 1957 (with P. P. Lombardini and R. F. Schwartz).

Measurement of the properties of various ferrites used in magnetically tuned resonant circuits in the 2.5–4.5 mc/s region. *J. Appl. Phys.*, **29**(3), 395–396, 1958 (with P. P. Lombardini and R. F. Schwartz).

Crystal deterioration studies. Final Report, The Institute for Cooperative Research, University of Pennsylvania, Report No. ES–28–030–05, 1958.

Microwave crystal deterioration studies. Final Report, Moore School of Electrical Engineering, Report 60–14, 1960.

Minimum pulse width obtainable from a magnetron. M.S. Thesis, University of Pennsylvania, 1959.

Temporary and permanent deterioration of microwave silicon crystal diodes. *Proceedings IRE*, **48**, 119, 1960 (with P. P. Lombardini).

Microwave crystal deteration studies. Final Report, Moore School of Electrical Engineering, Report No. 60–14, 1960.

Methods of improved measurement for electromagnetic field components. Report No. 2, Moore School of Electrical Engineering, Report No. 62–02, 1961.

TM modes in parallelogramic waveguides. *Proceedings IRE*, **49**(7), 1961 (with D. J. Lewis and P. P. Lombardini).

Study of methods of improved measurement for electromagnetic field components. Final Report, Moore School of Electrical Engineering, Report No. 62–19, 1962.

A sensitive recording system for harmonic pattern measurements at microwave frequencies. *Proceedings*, 7th Armour Conf. on Radio Interference Reduction and Elec. Compatibility, November, 584, 1961 (with D. J. Lewis).

Wave treatment of ionospheric propagation. Raytheon Company, Report No. BR–2238, 1962.

The study of the motion of wave packets in an inhomogeneous dissipative medium. Ph.D. Dissertation, University of Pennsylvania, 1963.

Wave treatment of ionospheric propagation. Interim Report, Raytheon Company, Report No. BR–2559, 1963.

Scattering properties of electron clouds. Interim Report, Raytheon Company, Report No. BR–2948, 1964.

Electromagnetic forward scattering of artificial electron clouds. 2nd Interim Report, Raytheon Company, Report No. BR–3051, 1964.

Analyses of linear arrays focused in the Fresnelregion. Raytheon Company, Report No. BR–3087, 1964 (with J. Goldhirsh and P. P. Lombardini).

Wide-band scatterer for point-to-point VHF link. Raytheon Company, Report No. FR–65–17. 1964 (with J. Goldhirsh and P. P. Lombardini).

Diagnostic measurements of the D-region using focused, ground-based antennas. Raytheon Company, Report No. FR–65–258, 1965 (with P. P. Lombardini and J. Goldhirsh).

Analysis of linear arrays focused in the Fresnel region. *Radio Sci.*, Sec. D., No. 7, 1965 (with P. P. Lombardini and J. Goldhirsh).

Electromagnetic scattering from electron irregularities embedded in an inhomogeneous electron density distribution. Raytheon Company, Report No. FR–65–275, 1965 (with J. Goldhirsh and P. P. Lombardini).

Isotropic microwave spark chambers for cosmic ray trace detection. Raytheon Company, Report No. FR–66–146, 1966 (with P. P. Lombardini and J. Goldhirsh).

Centimetric and millimetric wave spectroscopy of planetary atmospheres from orbital pairs. Raytheon Company, Report No. FR–66–242, 1966 (with J. Goldhirsh).

A note on the microwave spark chamber. *Nuclear Instruments and Methods*, **48**, 344, 1967 (with P. P. Lombardini and J. Goldhirsh).

A note on the threshold electric fields for microwave spark chambers. *Nuclear Instruments and Methods*, **54**, 161, 1967 (with P. P. Lombardini and J. Goldhirsh).

Radiation of short dipoles in the near zone of conduction cylinders. Symposium on Aviation Electronics, March 7, 1968 (with J. Goldhirsh, D. Knepp, and J. T. Lee).

Early warning of solar flares by observations of the sun disk at millimeter and submillimeter wavelengths. Raytheon Company, Report No. R68–4165, 1968 (with P. P. Lombardini and J. Goldhirsh).

Studies on the degradation of the omnidirectivity of antennas mounted near helicopter members. Tech. Symposium on Navigation and Positioning, ECOM, September 25, 1969 (with R. Unks, J. Goldhirsh and J. T. Lee).

Radiation pattern characteristics of a dipole near a thick conducting cylinder of resonant length. Tech. Symposium on Navigation and Positioning, ECOM, September 25, 1969 (with J. Goldhirsh).

Radiation from a dipole near a conduction cylinder of finite length. *IEEE Trans. Electromagn. Compat.*, **EMC–12**(3), 96, 1970 (with J. Goldhirsh and D. Knepp).

Radiation from a short dipole or monopole near a thick conducting cylinder of resonant length. *IEEE Trans. Antennas and Propag.*, **AP–19**(2), 279, 1971 (with J. Goldhirsh and D. Knepp).

Identification of layered and diffuse scattering regions using a bistatic radar probe. 971 USNC/URSI—IEEE Spring Meeting, Washington, D.C., April, 1971 (with J. Goldhirsh and A. R. Miller).

Time resolution of troposphere layers with the Valley Forge-Wallops Island forward scatter probe. *IEEE Trans. Antennas and Propag.*, 714–716, 1971 (J. Goldhirsh and A. R. Miller).

Comparison of bistatic and monostatic radar detection of clear air atmospheric targets. AIAA 10th Aerospace Sciences Meeting, San Diego, Calif., Paper No. 72–175, January 19, 1972.

Bistatic radar detection of the melting layer. *J. Appl. Meteor.*, **2**(6), 1012–1016, 1972 (with C. M. Weil).

Bistatic radar detection of high altitude clear air atmospheric targets. *Radio Sci.*, **7**(11), 993–1003, 1972 (with J. Goldhirsh and A. R. Miller).

Doppler radar with polarization diversity. *J. Atmos. Sci.*, **30**(4), 737–738, 1973 (with D. Sirmans).

Pulsed-Doppler velocity isotach displays of storm winds in real time. *J. Appl. Meteor.*, **12**(4), 694–697, 1973 (with D. Sirmans).

Meteorological radar signal intensity estimation. NOAA Tech. Memo. ERL NSSL–64, Norman, Okla., 1973 (with D. Sirmans).

Doppler velocity and reflectivity structure observed within a tornadic storm. *J. de Rech. Atmos.*, **3**(1–2), 235–243, 1974 (with D. W. Burgess, L. R. Lemon and D. Sirmans).

Real time Doppler isotach and reflectivity signature of a tornado cyclone. *Bull. Amer. Meteor. Soc.*, **55**(9), 1126–1127, 1974 (with D. Sirmans, D. W. Burgess and L. R. Lemon).

Velocity spectra of vortices scanned with a pulsed Doppler radar. *J. Appl. Meteor.*, **14**(8), 1531–1539, 1975 (with D. Zrnic).

Time, angle, and range sampling with weather radar. *Proceedings*, 16th Weather Radar Conf., Houston, Amer. Meteor. Soc., April, 156–162, 1975 (with P. S. Ray, D. Zrnic, and G. B. Walker).

Dual-Doppler observation of a tornadic storm. *J. Appl. Meteor.*, **14**(8), 1521–1530, 1975 (with R. S. Ray, G. B. Walker, D. Sirmans, J. Carter and W. C. Bumgarner).

Satellite borne Doppler radar measurement of atmospheric motion. NASA SP–376 Active Microwave Workshop Report, Lyndon B. Johnson Space Center, Houston, 318–335, 1975 (with R. Lhermitte, H. Groginsky and R. Weiss).

Tornado probing with a pulse-Doppler radar. *Proceedings*, Symposium on Tornadoes: Assessment of Knowledge and Implications for Man, June 22–24, Lubbock, Texas, 1976 (with D. Zrnic).

Error estimation in wind fields derived from dual-Doppler radar measurements. *J. Appl. Meteor.*, **15**(8), 868–878, 1976 (with P. S. Ray, R. Strauch, and J. Miller).

Effective antenna pattern of scanning radars. *IEEE Trans. Aerosp. and Electron. Syst.*, **AES–12** (5), 551–556, 1976 (with D. Zrnic).

R. Craig Goff

Meteorologist

Mr. Goff joined NSSL in July 1970. He provided technical meteorological supervision of the 461-m KTVY tower north of Oklahoma City, first instrumented for meteorological measurements in 1965. Objectives of the tower program center on better understanding of the planetary boundary layer interaction with severe local storms, including the dynamics, thermodynamics, and energetics of the boundary layer and their influence upon convective development.

Mr. Goff came to NSSL after receiving a Master's Degree in meteorology at Pennsylvania State University. His thesis examined dissipation of turbulent energy in the surface boundary layer using data from the Cape Kennedy, Florida, 150-m meteorological tower.

In 1972-1973, Mr. Goff took a one-year leave-of-absence from NSSL upon award of a NOAA Fellowship, and he received additional graduate training at the University of Oklahoma.

Important contributions by Mr. Goff include (a) climatological investigation of the planetary boundary layer, and (b) kinematical and dynamical study of the cold-air outflow from thunderstorms.

Educational Background

Liberal Arts, B.A. (1968), Minot State College, North Dakota

Meteorology, M.S. (1970), Pennsylvania State University

Additional meteorological graduate work toward Ph.D., University of Oklahoma

Professional Affiliation

American Meteorological Society

Publications and Reports

The thermal structure of the lowest half kilometer in central Oklahoma: December 9, 1966–May 31, 1967. NOAA Tech. Memo. ERL NSSL–58, Norman, Okla., 53 pp., 1972 (with H. R. Hudson).

Low-frequency temperature spectra from a 444 meter tower. *J. Atmos. Sci.*, **31**, 1164–1166, 1974 (with C. E. Duchon).

The NSSL/WKY–TV tower data collection program: April–July, 1972. NOAA Tech. Memo. ERL NSSL–68, Norman, Okla., 45 pp., 1974 (with W. D. Zittel).

Thunderstorm outflow kinematics and dynamics. NOOA Tech. Memo. ERL NSSL–75, Norman, Okla., 63 pp., 1975.

Some observations of thunderstorm induced low-level wind variations. *Proceedings*, Amer. Inst. of Aeronautics and Astronautics, Ninth Fluid and Plasma Dynamics Conf., San Diege. Calif., 8 pp., 1976.

Kathryn C. Gray

Manager, Computer and Data Processing

Mrs. Gray has managed NSSL's computer and data processing functions since 1964. Her early contributions included programming, data reduction, and arrangements for computer time at government facilities on the east and south U. S. coasts. Excess computers were used to establish "stop-gap" in-house computing facility, while feasibility studies provided for acquisiton of the excellent computing systems which presently serve the Laboratory.

From September 1975 through January 1976, Mrs. Gray was Acting DIRECTOR OF NSSL, managing administrative activities during the Director's absence. Mrs. Gray continues to serve in a central role at NSSL with respect to implementation and administration of policies; she manages our Computing and Data Processing Group, and she oversees dissemination of NSSL data to those requesting it for research from many places in the United States and overseas.

Earlier assignments with the U. S. Weather Bureau included pilot briefing, observing, rawinsonde, communications, and radar operations in Houston, Texas; Denver, Colorado; and Kansas City, Missouri. As archivist for the National Severe Storms Project in Kansas City, Mrs. Gray was responsible for research records and quality control procedures.

Other government positions involved unit accounting programming for Veterans Administration and Department of Defense, and commodity management (grain storage, preparation, and foreign shipments) for Department of Agriculture.

Education

Chemistry and Mathematics, B.A. (1947), Ottawa University and University of Houston
Law, LLB (1961), University of Colorado, Denver

Professional Affiliations

Member, Executive Board of the Systems Engineering Laboratories Computer User's Group.

Publications and Reports

Weather radar data system at the National Severe Storms Laboratory. *Preprints*, 5th Conf. on Severe Local Storms, St. Louis, Missouri, Oct. 19–20, 14–23, 1967 (with K. Wilk, D. Sirmans, W. Watts. R. Lhermitte, and E. Kessler).

Toward a quantitative radar echo climatology. *Proceedings*, 13th Radar Meteor. Conf., McGill University, Montreal, August, 280–285, 1968 (with E. Kessler, and J. T. Dooley).

Processing and analysis techniques used with the NSSL weather radar system. *Proceedings*, 14th Radar Meteor. Conf., Tucson, Arizona, Nov. 17–20, 369–374, 1970 (with K. Wilk).

Objectives and accomplishments of the NSSL 1975 spring program. Part 1: Observational program. NOAA Tech. Memo. ERL NSSL–78, 60 pp., 1976 (with K. Wilk and C. Clark).

Carl E. Hane

Meteorologist

Dr. Hane joined NSSL in June 1976. His long range objectives involve combining modeling and observing in studies of deep moist convection systems, including their interaction with their larger scale environments.

From 1973 to 1976 Dr. Hane was employed in the Atmospheric Sciences Department of Batelle-Northwest Laboratories, Richland, Washington. At Battelle he applied cloud models to precipitation scavenging problems. He studied redistribution of a pollutant plume by a thunderstorm circulation, to predict pollutant concentrations at various locations on the ground in the thunderstorm rainfall. In addition he was involved in (1) field experiment on precipitation scavenging by thunderstorms, within project METROMEX, (2) precipitation scavenging in frontal storms as a co-leader of field experiments, (3) application of a one-dimensional cloud model to cooling tower plumes, and (4) application of a two-dimensional cloud model to heat release from proposed energy centers (parks).

Dr. Hane's professional experience began in 1963 with appointment as a Weather Bureau Student Trainee. During three-month periods (summer) 1963–64, he worked at the Weather Bureau Office, Topeka, Kansas, and in 1965–66 with the National Severe Storms Forecast Center, Kansas City, Missouri. Upon graduation from Florida State University in 1972 he was awarded a postdoctoral appointment for one year at the National Center for Atmospheric Research. There he continued working with a two-dimensional time-dependent convective cloud model formulated at

Florida State during his dissertation research. He applied the model to warm-season convection over the southeastern United States and to the calculation of dropsonde trajectories in connection with the National Hail Research Experiment.

Dr. Hane attended public schools in Leavenworth, Kansas, graduating in 1961 when he was valedictorian of his high school class. Award of a NASA traineeship at Florida State University in 1966 facilitated his graduate studies in meteorology.

Educational Background

Mathematics, B.A. (1966), Meteorology, B.S. (1966), University of Kansas, Lawrence
Meteorology, M.S. (1968), Ph.D. (1972), Florida State University, Tallahassee

Professional Affiliations

American Meteorological Society
Phi Kappa Phi

Publications and Reports

Squall line maintenance: preliminary numerical investigations. Report No. 70–6, Prepared under Grant E 22–15–70 (G) with ESSA, 13 pp., 1970.

Squall line structure and maintenance: numerical experimentation. Report No. 72–5, Prepared under Grant E 22–19–71 (G) and E 22–58–69 (G) with NOAA, 190 pp., 1972.

A numerical model of the Great Plains squall line thunderstorm. *Preprints*, Eighth Conf. on Severe Local Storms, Denver, Colo., October 15–17, 257–264, October, 1973.

The squall line thunderstorm: numerical experimentation. *J. Atmos. Sci.*, **30**, 1672–1690, 1973.

Convective storm modeling and its possible application to precipitation scavenging problems. Pacific Northwest Laboratory Annual Report for 1973 to the USAEC Division of Biomedical and Environmental Research, 143–146, 1974.

Precipitation scavenging of inorganic pollutants from metropolitan sources. Report to the Office of Research and Development, U. S. Environmental Protection Agency, 136 pp., 1974 (with M. T. Dana, J. M. Hales, and J. M. Thorp).

Precipitation scavenging in a squall line: numerical experimentation. *Precipitation Scavenging*—1974, R. W. Beadle and R. G. Semonin (Coords.), AEC Symposium Series, Champaign, Ill., 1974.

Atmospheric effects of circular mechanical draft cooling towers at Washington Public Power Supply System Nuclear Power Plant Number Two. Report to Burns and Roe, Inc., 38 pp., 1975 (with J. G. Droppo and R. K. Woodruff).

The trajectories of dropsondes in simulated thunderstorm circulations. *Mon. Weather Rev.*, **103**, 709–716, 1975.

Dropsonde trajectories in simulated thunderstorm circulations. *Preprints*, Ninth Conf. on Severe Local Storms, Norman, Okla., October, 1975.

Precipitation scavenging field experiments in March 1975 on the Olympic Peninsula. Pacific Northwest Laboratory Annual Report for 1975 to the USERDA–DBER, 147–150, 1976 (with J. A. Young).

Design for in-cloud scavenging experiments on the Olympic Peninsula. Pacific Northwest Laboratory Annual Report for 1975 to the USERDA–DBER, 151–155, 1976 (with J. A. Young).

A review of moist mesoscale models with possible applicability to precipitation scavenging. Pacific Northwest Laboratory Annual Report for 1975 to the USERDA–DBER, 156–159, 1976.

Scavenging of urban pollutants by thunderstorm rainfall: numerical experimentation. Pacific Northwest Laboratory Annual Report for 1975 to the USERDA–DBER, 172–178, 1976.

Preparation of hourly maps of gridded precipitation data for use in precipitation scavenging calculations. Pacific Northwest Laboratory Annual Report for 1975 to the USERDA–DBER, 229–232, 1976 (with L. L. Wendell).

Larry Hennington

Electronic Engineer

From 1971 to the present, Mr. Hennington has been a computer specialist for NSSL. He has developed and maintained hardware and software for a minicomputer real-time data processing and display system interfaced to one of NSSL's Doppler radars. Prior to 1970 he was employed in several technical support positions such as Field Engineering Representative (General Electric/Honeywell) and Electronic Technician (U. S. Navy).

Mr. Hennington's achievements include design and implementation of the multimoment Doppler display which is used to detect mesocyclones and tornado vortex signatures easily in real time.

Educational Background

Electrical Engineering, B.S. (1975), University of Oklahoma, Norman
Graduate studies, University of Oklahoma, Norman

Publications and Reports

Simulated real time displays of Doppler radar velocity fields. NOAA Tech. Memo. ERL NSSL–60, Norman, Okla., 1972 (with G. Walker).

Multimoment Doppler display for severe storm identification. Accepted by *J. Appl. Meteor.*, 1976 (with D. Burgess, P. S. Ray, and R. J. Doviak).

Measurements of winds in the optically clear air with microwave pulse-Doppler radar. *Preprints*, 17th Radar Conf., Seattle, Wash., October 26–29, 1976 (with R. J. Doviak, D. Sirmans, D. Zrnic, and R. G. Strauch).

Estimates of power scattered from distributed targets for a practical logarithmic detector. *Preprints*, 17th Radar Conf., Seattle, Wash., October 26–29, 1976 (with G. B. Walker and D. Sirmans).

Edwin Kessler

Director

Dr. Kessler has been Director of NSSL since the Laboratory was organized in 1964. In cooperation with other groups, the Laboratory seeks understanding of tornadoes, squall lines, thunderstorms, and related local storms and rain; develops and applies methods for their observation and prediction; and examines possibilities for their beneficial modification.

Before joining NSSL, Dr. Kessler was Director of the Atmospheric Physics Division in the Travelers Research Center, Hartford, Connecticut. There he developed a theory of associations among distributions of water vapor, cloud and precipitation, microphysical processes, and the wind field, and authored specifications for computer programs to assemble and analyze patterns of radar-weather data.

From 1954 to 1961, Dr. Kessler worked at the Weather Radar Branch, Air Force Cambridge Research Laboratories, Bedford, Massachusetts, where he was Chief of the Synoptic Meteorology Section. In this post, he studied interpretation of weather-radar data in terms of atmospheric fields of motion, water content, and temperature, and the data's application to weather forecasting. He invented an instrument to facilitate accurate measurement of radar-reflectivity distributions. Dr. Kessler also monitored the GRD contractual program in radar-synoptic meteorology.

Dr. Kessler's most important contributions include (1) development of a theory for the distribution of water substance in atmospheric circulations; (2) development of improved techniques for acquiring, processing, and applying weather radar data; and (3) management of the National Severe Storms Laboratory from 1964 to the present time.

Educational Background

General Science and Mathematics, A.B. (1950), Columbia College, New York City

Meteorology, S.M. (1952), Sc.D. (1957), Massachusetts Institute of Technology

Professional Affiliations

American Meteorological Society:
- Fellow of the Society; past president, Greater Boston Branch; National Councilor, 1966–1969; Certified Consulting Meteorologist; past Member of Committee on Severe Local Storms; past Chairman of Committee on Weather Radar; Associate Editor, *Journal of Applied Meteorology*

Royal Meteorological Society

Sigma Xi

American Geophysical Union

American Association for the Advancement of Science, Fellow

Weather Modification Association

Executive Committee, Oklahoma University Research Institute

Commission F of the International Union of Radio Science

Adjunct Professor, University of Oklahoma, 1964–present

Visiting Professor, Massachusetts Institute of Technology, Sept. 1975–Feb. 1976

Publications and Reports

Curvature corrections for radiowind reports. *Bull. Amer. Meteor. Soc.*, **35**(7), 328–330, 1954.

On the relation between the received signal level of the Homdel-Round Hill circuit and certain meteorological parameters. Rept., Dept. of Meteor., M.I.T., to Lincoln Laboratory, 16 pp., 1954.

A test of the application of vorticity charts. *Bull. Amer. Meteor. Soc.*, **36**(6), 251–255, 1955 (with F. Sanders).

Radar synoptic analysis of Hurricane Edna, 1954. *Geophys. Res. Paper* 50, Air Force Cambridge Research Center, 1956 (with D. Atlas).

A model atmosphere for widespread precipitation. *Aeronaut. Eng. Rev.*, **16**(2), 69–75, 1957 (with D. Atlas).

Reflectivities from unmodified radar displays. *Proceedings*, 6th Weather Radar Conf., Cambridge, March 26–28, 1975, Amer. Meteor. Soc., 315–320.

Outer precipitation bands of hurricanes Edna and Ione. *Bull. Amer. Meteor. Soc.*, **38**(6), 335–346, 1957.

Radar-synoptic analysis of an intense winter storm. *Geophy. Res. Paper* 56, Air Force Cambridge Research Center, 1957.

Eye region of Hurricane Edna, 1954. *J. Meteor.*, **15**(3), 264–270, 1958.

Fields of motion and temperature in hurricanes as revealed by radar. *Proceedings*, Tech. Conf. on Hurricanes, Amer. Meteor. Soc.: and *Proceedings*, 7th Weather Radar Conf., Amer. Meteor. Soc., 1958.

The PAR-Scope, an oscilloscope display for weather radars. *IRE Trans. Aeronaut. and Navigational Electron.*, **ANE–6**(1), 31–36, 1959.

Model precipitation distributions. *Aero/Space Eng.*, **18**(12), 36–40, 1959 (with D. Atlas).

Kinematical relations between wind and precipitation distributions. *J. Meteor.*, **16**(6), 630–637, 1959.

Observations of a cold front, October 1, 1958. *Bull. Amer. Meteor. Soc.*, **41**(5), 253–257, 1960 (with R. Wexler).

Application of radar to the study of hurricanes. *Proceedings*, 2nd Tech. Conf. on Hurricanes, National Hurricane Research Project, Miami, Fla., 1961.

Kinematical relations between wind and water distributions, II. *J. Meteor.*, **18**(4), 510–525, 1961.

Appraisal of the use of radar in observation and forecasting. *Proceedings*, Ninth Weather Radar Conf., 1961, Amer. Meteor. Soc., 23 pp.

Report concerning test flight with APS–20E radar and its suggested uses for hurricane and thunderstorm reconnaissance. Report to U. S. Weather Bureau under Contract Cwb–10041, 15 pp., 1962.

Elementary theory of associations between atmospheric motions and distributions of water content. *Mon. Wea. Rev.*, **91**(1), 13–28, 1963.

Relationships between tropical precipitation and kinematic cloud models. Presented at 43rd Annual Meeting of Amer. Meteor. Soc., 1963; Reports No. 1, 2, 3, 4, and 5 on Dept. of the Army Contract DA36–039 SC 89099, 15 pp., 1963 (with P. Feteris and Newbury).

Use of radar summary maps for weather analysis and forecasting. *J. Appl. Meteor.*, **2**(1), 1–11, 1963 (with J. W. Wilson).

Note on the range normalization of digitized radar data. *J. Appl. Meteor.*, **2**(1), 178–180, 1963.

Statistical properties of weather radar echoes. *Proceedings*, 10th Weather Radar Conf., April, 9 pp., 1963 (with J. A. Russo).

Program for the assembly and display of radar-echo distributions. *J. Appl. Meteor.*, **2**(5), 582–593, 1963 (with J. A. Russo).

An experimental Doppler radar for severe storm investigations. *Proceedings*, 1964 World Conf. on Radio Meteor., incorporated with 11th Weather Radar Conf., Amer. Meteor. Soc., Boston, 1964, 304–309 (with R. M. Lhermitte).

On membership structure. *Bull. Amer. Meteor. Soc.*, **45**(5), 279, 1964.

Purposes and programs of the National Severe Storms Laboratory. Report No. 23 of the NSSP–NSSL series, 17 pp.; Also *Trans. AGU*, **46**(2), 389–397, 1965.

Weather detection by ARSR–ID, ASR–4, and WSR–57 radars: a comparative study. NSSL Tech. Memo. No. 1, Norman, Oklahoma, 33 pp., 1965 (with K. E. Wilk and J. T. Dooley).

Sferics reception at 500 Kc/sec, radar echoes and severe weather. Final Report to FAA under interagency agreement FA64–WAI76, 43 pp.; Also National Severe Storms Laboratory Report No. 24, 39–71, 1965 (with N. B. Ward and C. H. Meeks).

A weather radar signal integrator. *Proceedings*, International Conf. on Cloud Physics, Tokyo and Sapporo, 302–308; also NOAA Tech. Memo. ERL NSSL–2, Norman, Oklahoma, 1965 (with R. M. Lhermitte).

Microphysical parameters in relation to tropical cloud and precipitation distributions and their modification. Third Conf. on Tropical Meteorology and Hurricanes, Mexico City, June 6–12, 1963.

Associations between aircraft measurements of turbulence and weather radar measurements. *Bull. Amer. Meteor. Soc.*, **46**(8), 443–447, 1965; Also 45th Annual AGU Meeting, April 23, 10 pp., 1964 (with J. T. Lee and K. Wilk).

A storm's incalculable energy. *Natural History*, **75**(4), 6 pp., 1966.

Lightning discharge and precipitation. *Q.J.R. Meteor. Soc.*, **92**(392), 308–310, 1966.

Measurements by aircraft of condensed water in Great Plains thunderstorms. Report No. 19 of the former National Severe Storms Project, 17 pp., 1966 (with G. P. Roys).

Radar measurements for the assessment of areal rainfall: Review and outlook. *Water Resources Res.*, **2**(3), 413–425, 1966; also presented at the 17th Session of the WMO Executive Committee, Geneva, 1965.

Distribution with height of the radar echo coverage and its meteorological significance. *Proceedings*, 12th Conf. on Radar Meteorology, 52–56, 1966.

Community preparedness in a place of high tornado frequency. *Proceedings*, 12th Conf. on Radar Meteorology, 35–36, 1966.

Estimation of the average intensity of precipitation targets. *Proceedings*, 12th Conf. on Radar Meteorology, 5–9, 1966 (with R. M. Lhermitte).

Computer program for calculating average lengths of weather radar echoes and pattern bandedness. *J. Atmos. Sci.*, **23**(5), 569–574, 1966; also ESSA Tech. Note 3–NSSL–24, 99–110, 1965.

On the continuity of water substance. NOAA Tech. Memo. ERL NSSL–33, ESSA, Boulder, Colo., 125 pp., 1967.

Weather radar data system at the National Severe Storms Laboratory. *Proceedings*, Conf. on Severe Local Storms, St. Louis, October 19, 1967; also Tech. Circular No. 4, NSSL, 1967 (with K. Wilk, W. Watts, D. Sirmans, R. Lhermitte and K. Gray).

Aerial cloud photography as a technique for observing cloud growth and development. *Proceedings*, 1st National Conf. on Weather Modification, Albany, April, Amer. Meteor. Soc., 343–349, 1968 (with J. T. Lee).

Evaluation of meteorological situation near Dawson, Texas, 3 May 1968. 24 pp., 1968 (with Staff of NSSL, ESSA).

Radar measurement of precipitation for hydrological purposes. Report No. 5, of the WMO series on the International Hydrological Decade, World Meteor. Organization, Geneva, Switzerland, 1968 (with K. E. Wilk).

Toward a quantitative radar echo climatology. *Proceedings*, 13th Radar Meteor. Conf., Montreal, August 20–23, 1968, 280–285 (with K. Gray and J. T. Dooley).

Remarks on the study of precipitation formation. *Proceedings*, International Conf. on Cloud Physics, Amer. Meteor. Soc., 336–339, 1968.

Growth by accretion in relation to hydrometeor starting height, cloud density, and vertical air velocity. *Proceedings*, International Conf. on Cloud Physics, Toronto, August 26–30, 464–471, 1968 (with E. A. Newburg and J. Silver).

On the distribution and continuity of water substance in atmospheric circulations. *Meteorological Monographs*, **10**(32), 84 pp., 1969.

Thunderstorms over Oklahoma—22 June 1969. *Weatherwise*, **23**(2), 56–69, 1970.

Tornadoes. *Bull. Amer. Meteor. Soc.*, **51**(10), 926–936, 1970.

Quantitative radar measurements of precipitation. *Meteor. Monographs*, **11**(33), 315–329, 1970 (with K. E. Wilk).

Uncertainty of quantized estimates of radar echo intensity. *Preprints*, 14th Radar Meteor. Conf., Tucson, November 14–20, 381–382, 1970 (with D. Sirmans).

Radar in an automated national weather system. *Bull. Amer. Meteor. Soc.*, **52**(11), 1062–1069, 1971 (with J. W. Wilson).

Model of precipitation and vertical air currents. NOAA Tech. Memo. ERL NSSL–54, Norman, Okla., 93 pp., 1971 (with W. C. Bumgarner).

Storm detection. In *McGraw-Hill Encyclopedia of Science and Tech.*, **13**, 180–183, 1971.

On tornadoes and their modification. *Technology Review*, **74**(6), 11 pp., 1972.

Seedability in relation to environmental parameters and the horizontal dimension of convective events. *Preprints*, Third Conf. on Weather Modification, Rapid City, June 26–29, Amer. Meteor. Soc., 195–198, 1972.

High level stratocumulus. *Weather*, **27**(10), 433, 1972.

On interpretation of data from meteorological Doppler radars. *Preprints*, 15th Radar Meteor. Conf., Champaign-Urbana, Illinois, October 10–12, 231–232, 1972.

On the artificial increase of precipitation. *Weather* **28**(5), 188–194, 1973; also a version presented November 9, 1972, Symposium on Weather Modification, Oklahoma Disaster Preparedness Conf., Oklahoma City.

Radar for rainfall monitoring. Presented at AAAS National meeting, San Francisco. February 27, 11 pp., 1974 (with K. E. Wilk).

Survey of boundary layer winds with special reference to extreme values. AIAA Paper No. 74–586, 7th Fluid and Plasma Dynamics Conf., Palo Alto, June 17–19, 19 pp., 1974.

Tornadoes. *Weather and Climate Modification*, edited by W. N. Hess, John Wiley & Sons, New York, 1974, 552–595 (with R. P. Davies-Jones).

Weather modification and severe local storms. *Proceedings*, Semicentennial Observance of Texas Tech Univ., October 15, 12 pp., 1974.

Model of precipitation and vertical air currents. *Tellus*, **26**(5), 519–542, 1974.

Some applications of weather radar to problems of energy production. *Remote Sensing, Energy Related Studies*, edited by T. Nejat Veziroglu, Halsted Press (John Wiley & Sons), New York, 103–112, 1975.

Condensate content in relation to sloping updraft parameters. *J. Atmos. Sci.*, **32**(2), 443–444, 1975.

Soaring vultures use a dust devil to gain altitude. *The Wilson Bulletin*, **87**(1), 113–114, 1975.

Development of Beekeeping Ordinance in Norman, Oklahoma. *Gleanings in Bee Culture*, **103**(8), 268–269, 1975.

On the condensed water mass in rising air. *Pure and Appl. Geophys.*, Special Issue: Cloud dynamics, Edited by Hans R. Pruppacher, **113**(5/6), 971–981, 1975. Abbreviated version in *Preprints*, Ninth Conf. on Severe Local Storms, Norman, October 21–23, 1975, AMS, 199–202.

Tornado forum. Letter in *Nature*, **260**(5550), 457, 1976. (Response to article by Isaacs et al.)

Weather modification and severe local storms. *Proceedings*. Symposium on Frontiers of the Semi-Arid World, Lubbock, Texas, October 14–18, 1974, Vol. 2 (*Weather Modification Research Studies*, Texas Tech V.) 65–77.

Normalized indices of destruction and deaths by tornadoes. NOAA Tech. Memo. ERL NSSL–77, 47 pp., 1976 (with J. T. Lee).

Jean T. Lee

Meteorologist

Mr. Lee has been with NSSL since it was organized in 1964. His research on storm hazards to aviation has involved participation by NASA, FAA, and USAF, and has provided substantial contributions to the safety and economy of flight. An FAA circular on thunderstorm flying based largely on the NSSL research is a definitive guide to aviation everywhere. During the early years at NSSL, Mr. Lee doubled as Administrative Officer, and by virtue of his substantial experience and good judgment he has always had important responsibilities for coordination of programs with other agencies.

From 1959 through 1964, Mr. Lee was a research meteorologist with the U.S. Weather Bureau's National Severe Storms Project, the forerunner of NSSL. From 1954 to 1959 Mr. Lee was a severe local storms forecaster responsible for tornado and severe storm forecasts in the continental U.S. Between 1950 and 1954 he was an Educational Specialist in the Weather Bureau central office. During this time he developed a pilot briefer course and revised a book, *Meteorology for Pilots*.

Mr. Lee first entered civilian government service in 1947 as an Aviation Forecaster at Jacksonville, Florida. Previously he had taught mathematics and physics at the University of Southern Mississippi; his military service was as a station weather officer in the continental United States and in the South Pacific.

In 1958, Mr. Lee received a Department of Commerce silver medal group award for contributions to advancement of severe storm prediction.

Educational Background

Physics, Math, and Secondary Education (1940-43), University of Wisconsin

Meteorology, B.S. (1944), M.S. (1962), University of Chicago

Professional Affiliations

American Meteorological Society

American Association for the Advancement of Science

Publications and Reports

A short course in meteorology for observer-briefers. U.S.W.B. Training Paper, 1951.

Training course for pilot briefers. U.S.W.B., 1952 (with T. Tule and C. Reber).

Pilot's weather handbook. CAA Tech. Manual No. 104, 143 pp., 1954, 2nd ed., 1955 (with C. Reber).

Tornadoes of February 1, 1955. *Mon. Weather Rev.*, **83**(2), 45–51, 1955.

Preliminary report on the relationship between the jet at the 200 mb level and tornado occurrence. *Bull. Amer. Meteor. Soc.*, **37**(7), 327–332, 1956 (with J. Galway).

Forecasting tornadoes and severe thunderstorms. U.S.W.B. Forecasting guide No. 1, 34 pp., 1965 (with SELS Staff).

The jet chart. *Bull. Amer. Meteor. Soc.*, **39**(4), 217–223, 1958 (with J. Galway).

Tornadoes in the United States, 1950–1956. *Mon. Wea. Rev.*, **86**, 219–228, 1958.

The synoptic situation—the tornadoes at Dallas, Texas, April 2, 1957. U.S.W.B. Research Paper No. 41, 114–143, 1960.

A case study of extreme turbulence possibilities based on considerations of buoyancy and horizontal divergence. *Bull. Amer. Meteor. Soc.*, **42**(3), 175–185, 1961 (with D. C. House).

The tornado research airplane project 1958–1959. *Bull. Amer. Meteor. Soc.*, **42**(4), 231–238, 1961 (with C. L. David).

Squall line structure and development as depicted by horizontal traverses by the tornado research aircraft. *Bull. Amer. Meteor. Soc.*, **42**(9), 595–602, 1961 (with C. L. David).

A summary of field operations and data collection by the National Severe Storms Project in spring 1961. NSSP Report No. 5, 47 pp., 1961.

A plan for research on mesoscale severe storms. Univ. of Chicago, M.S. Thesis, 47 pp., 1962.

Thunderstorm turbulence measurements by aircraft and concurrent radar echo evaluations. Unit I of Final Report, Severe Storms Detection and Circumnavigation, FAA Contract ARDS–A–176, 1–56, 1963.

NSSP Final Report on NASA Project No. R–55, 65 pp., 1963.

Environmental and thunderstorm structures as shown by National Severe Storms Project observations in spring 1960 and 1961. *Mon. Wea. Rev.*, **9**(6), 271–292, 1963 (with NSSP Staff).

Field operations of the National Severe Storms Project in spring 1963. NSSP Report No. 20, 68 pp., 1964 (with L. D. Sanders).

Associations between aircraft measurements of turbulence and weather radar measurements. 45th Annual Meeting AGU–AMS, April 23, 10 pp., 1964 (with E. Kessler and K. Wilk).

Thunderstorm turbulence and radar echo relationships; 1964 Data Studies. *Proceedings*, Fifth Annual National Conf. on Environmental Effects on Aircraft and Propulsion Systems, September 1965.

F–100 observations of thunderstorm turbulence between 20,000–40,000 feet. *Proceedings*, Sixth Annual National Conf. on Environmental Effects on Aircraft and Propulsion Systems, September 1966.

Associations between atmospheric turbulence and radar echoes in Oklahoma. *Proceedings*, Twelfth Conf. on Radar Meteor., October 1966.

Thunderstorm circulations and turbulences from aircraft and radar data. ESSA Tech. Memo. IERTM–NSSL–32, 1967.

Aerial cloud photography as a technique for observing cloud growth and development. *Proceedings*, First National Conf. on Weather Modification, Albany, New York, April 1968 (with E. Kessler).

Thunderstorm turbulence and its relationship to weather radar echoes. *AIAA J. Aircraft,* **6**(5), 438–445, 1969 (with J. Burnham).

Thunderstorm turbulence. *Proceedings*, Symposium on Turbulence, Washington, D.C., March, 10 pp., 1971.

Comparison of thunderstorms over Oklahoma and Malaysia based on aircraft measurements. *Proceedings*, International Conf. on Atmospheric Turbulence, London, England, May, 13 pp., 1971 (with A. McPherson).

Aerial survey of tornado producing thunderstorms. *Proceedings*, Seventh Conf. on Severe Storms, Kansas City, Missouri, October, 49–53, 1971.

Thunderstorm turbulence and drafts. *Proceedings*, Int. Conf. on Aerospace and Aeronautical Meteor., Amer. Meteor. Soc., AIAA, WMO, and ICAO, Washington, D.C., May, 276–280, 1972.

Application of Doppler weather radar to turbulence measurements that affect aircraft. FAA Report RD–74–97, 24 pp., 1974.

Thunderstorm turbulence—concurrent Doppler radar aircraft observations, 1973. *Proceedings*, Sixth Conf. on Aerospace and Aeronautical Meteor., El Paso, Texas, Amer. Meteor. Soc., November, 295–298, 1974.

Plan shear indicator and aircraft measurements of thunderstorm turbulence: experimental results. *Preprints*, 16th Radar Meteor. Conf., Houston, Texas, Amer. Meteor. Soc., April 22–24, 337–340, 1975 (with M. Kraus).

Mesoscale cloud features observed from skylab. NASA Report TMS 58142, Chapter 18, 1975 (with D. Pitts and Y. Sasaki).

Normalized indices of destruction and death by tornadoes. NOAA Tech. Memo. ERL NSSL–77, Norman, Oklahoma, 1976 (with E. Kessler).

Leslie R. Lemon

Meteorologist

From February 1973 to March 1976 Mr. Lemon was employed at NSSL; at the beginning he was a Lieutenant in the NOAA Commissioned Corps. Mr. Lemon worked extensively with conventional and Doppler radar data to produce diagnostic models to explain severe convective storm structure and processes.

Before joining NSSL in 1973, Mr. Lemon served in the NOAA Corps aboard the ship *Researcher*. His primary duties were supervising weather observing and transmission duties, training personnel in weather observing, and providing meteorological forecasts for the ship's working areas.

From 1968 through March 1970, Mr. Lemon was a physical science aid and meteorological technician at NSSL while a student at the University of Oklahoma.

Mr. Lemon's most important contributions include (1) discovery of the Doppler radar Tornadic Vortex Signature for which he received a special achievement award; (2) discovery of the anticyclonic wake vortex associated with severe thunderstorms; and (3) contributions to understanding of effects of flanking convection on existing severe thunderstorms, and delineation of severe thunderstorm surface meteorological structure. Currently, Mr. Lemon is continuing his work at the Techniques Development Unit, National Severe Storms Forecast Center, Kansas City, Missouri.

Educational Background

Meteorology, B.S. (1970), University of Oklahoma
Kansas City Jr. College, and University of Kansas

Professional Affiliations

American Meteorological Society
Sigma Tau (Engineering Fraternity)

Publications and Reports

Formation and emergence of an anticyclonic eddy within a severe thunderstorm as revealed by radar and surface data. *Preprints*, 14th Conf. on Radar Meteor., Tucson, Arizona, Amer. Meteor. Soc., 323–328, 1970.

Observations of Doppler isotach and reflectivity structure within tornadic storms. *Preprints*, Inter-union Commission of Radio Meteorology Colloquium, Nice, France, 1973 (R. J. Doviak, D. W. Burgess, and D. Sirmans).

Doppler velocity and reflectivity structure observed within a tornadic storm. *J. Rech. Atmos.*, **8**(1–2), 235–243, 1973 (with R. J. Doviak, D. W. Burgess and D. Sirmans).

Interaction of two convective scales within a severe thunderstorm: a case study; and Thunderstorm wake vortex structure and aerodynamic origin. NOAA Tech. Memo. ERL NSSL–71, Norman, Oklahoma, 43 pp., 1974.

Real time Doppler isotach and reflectivity signature of a tornado cyclone. *Bull. Amer. Meteor. Soc.*, **55**, 1126–1127, 1974 (with D. Sirmans, R. J. Doviak and D. W. Burgess).

Evolution of a tornado signature and parent circulation as revealed by single Doppler radar. *Preprints*, Radar Meteor. Conf., Houston, Texas, Amer. Meteor. Soc., 99–106, 1975 (with D. W. Burgess and R. A. Brown).

Tornado characteristics revealed by Doppler radar. *Geophys. Res. Lett.*, **2**, 183–184, 1975 (with D. W. Burgess and R. A. Brown).

NSSL dual-Doppler radar measurements in tornadic storms: a preview. *Bull. Amer. Meteor. Soc.*, **56**, 524–526, 1975 (with R. A. Brown, D. W. Burgess, J. Carter, and D. Sirmans).

Tornado production and storm sustenance. *Preprints*, Ninth Conf. on Severe Local Storms, Norman, Oklahoma, Amer. Meteor. Soc., 100–104, 1975 (with D. W. Burgess and R. A. Brown).

Analysis of the 4 June 1973 Norman tornadic storm. *Preprints*, Ninth Conf. on Severe Local Storms, Norman, Oklahoma, Amer. Meteor. Soc., 384–388, 1975 (with R. P. Davies-Jones and D. W. Burgess).

The flanking line, a severe thunderstorm intensification source. *J. Atmos. Sci.*, **33**(4), 686–694, 1976.

Wake vortex structure and aerodynamic origin in severe thunderstorms. *J. Atmos. Sci.*, **33**(4), 678–685, 1976.

Stephan P. Nelson

Meteorologist

Since March 1972, Mr. Nelson has served in NSSL's Meteorology Research Project. Major duties include development of data collection/analysis techniques and interpretation of surface mesonetwork, rawinsonde, and radar data on severe storms. Recent effort has been directed toward investigation of relationships between microphysical and dynamical processes in storms.

From 1969 till 1972, Mr. Nelson was a research assistant at the University of Chicago Cloud Physics Laboratory. There he interpreted radar storm data, collected and analyzed air pollution data (Project METROMEX), helped install and operate the TPS–10 radar, analyzed weather modification data (Project Whitetop), and participated in operational flights and maintained airborne meteorological instrumentation. His work at Chicago and with joint NSSL/University of Oklahoma projects has included over 100 hours of research flight.

During summer 1969 Mr. Nelson was employed at the Navy Weather Research Facility, Norfolk, Virginia, where he helped develop forecast ing techniques.

In 1974–1975, Mr. Nelson used a NOAA Fellowship to obtain additional graduate training at the University of Oklahoma.

Educational Background

Meteorology and Oceanography, B.S. (1969), New York University
Meteorology, S.M. (1971), University of Chicago
Additional graduate studies, University of Oklahoma

Professional Affiliations

American Meteorological Society
American Geophysical Union

Publications and Reports

Detailed observational study of an echo free region. *Preprints*, 15th Radar Meteor. Conf., Champaign-Urbana, October 10–12, Amer. Meteor. Soc., 50–57, 1972 (with R. R. Braham).

Radiosonde altitude measurement using double radiotheodolite techniques. NOAA TEch. Memo. ERL NSSL–65, Norman, Okla., 20 pp., 1973.

Experiments to deduce tornado cyclone inflow characteristics using chaff and NSSL dual-Doppler radars. *Bull. Amer. Meteor. Soc.*, **55**(9), 1130–1131, 1974 (with J. McCarthy and G. Heymsfield).

Study of a dissipating severe storm. NOAA Tech. Memo. ERL NSSL–69, Norman, Okla., 89–96, 1974 (with S. L. Barnes).

Detailed observational study of a weak echo region. *Pure and Appl. Geophys.*, **113**(5–6), 735–746, 1975 (with R. R. Braham).

Evolution of a tornadic cyclone as seen by dual-Doppler, instrumented aircraft and chaff. *Preprints*, 9th Conf. on Severe Local Storms, Norman, Oklahoma, October 21–23, Amer. Meteor. Soc., Boston 389–395, 1975 (with J. McCarthy, G. Heymsfield, and L. Tidwell).

Characteristics of multicell and supercell hailstorms in Oklahoma. Second WMO Conf. on Wea. Modif., Boulder, August 2–6, WMO–No. 443, 335–340, 1976.

Edward T. Pierce

Physical Scientist

Dr. Pierce joined NSSL as Senior Scientist in April 1976. He is leading development of a program in storm electricity.

Before joining NOAA, Dr. Pierce was for many years a Staff Scientist and Scientific Advisor at Stanford Research Institute (SRI) California. Here he carried out research in atmospheric electricity, radio physics, gas discharge phenomena and the geophysical effects of nuclear explosions. Highlights of the period at SRI include expert testimony before Congress prior to the Nuclear Test-Ban Treaty of 1963; establishment of a Scientific Liaison Group for the Office of Naval Research at the Tokyo Embassy; and research into the electrostatic hazards causing supertanker explosions and endangering the NASA series of Apollo rocket launches.

From 1946 to 1957, Dr. Pierce was on the faculty of the University of Cambridge, England. Here he conducted and supervised research in solar and meteorological physics; he also gave courses of postgraduate lectures. Dr. Pierce has also been employed by AVCO Corporation (1959–1960; geophysics research), by Vickers Ltd. (1957–1958; high voltage research) and by the British Government (1940–1945; weapons research).

Dr. Pierce's most important contributions are based in his (1) scientific publications principally in atmospheric electricity and radio physics; (2) reports colligating and applying basic scientific information; and (3) participation in international science.

Educational Background

Mathematics, B.Sc (Summa Cum Laude, 1937), University of Wales

Physics, B.Sc (Summa Cum Laude, 1938), University of Wales

Atmospheric Physics, Ph.D. (1951), University of Cambridge, England

Professional Affiliations

American Meteorological Society
Past Chairman, Committee on Atmospheric Electricity

American Geophysical Union

International Union of Geodesy and Geophysics (UGGI)

International Union of Radio Science (URSI)

Inter-Union (UGGI-URSI)—Commissions

Royal Meteorological Society, Past Councillor

Society of Terrestrial Magnetism and Electricity of Japan

International Commission on Atmospheric Electricity
Honorary President 1975 to present

Publications and Reports

Solar limb flare. *Nature*, **160**, 59, 1947.

Atmospherics. *J.I.E.E.*, **95**(3), 381, 1948 (with T. W. Wormell).

The waveforms of atmospherics. *Phil. Mag.*, **43**, 393–409, 1952 (with P. G. F. Caton).

The radiolocation of thunderstorms. *Bull. Amer. Meteor. Soc.*, **33**, 243, 1952

On atmospherics containing a low-frequency component or an extended series of oscillations. *Proc. U.R.S.I.*, Sydney, Australia, 1952 (with F. Hepburn).

Four working papers on atmospherics for the World Symposium of Sferics, Zurich, Germany, 1953.

Atmospheric waveforms and the location of thunderstorms. *Proceedings*, Conf. on Radio-Meteorology, University of Texas, 1953 (with T. W. Wormell).

Field-changes due to lightning discharges. *Thunderstorm Electricity*, edited by H. R. Byers, University of Chicago Press, Chicago, Illinois, 251–266, 1953 (with T. W. Wormell).

Atmospherics with very low frequency components. *Nature*, **171**, 837–838, 1953 (with F. Hepburn).

Atmospherics with long trains of pulses. *Phil. Mag.*, **45**, 917–931, 1954 (with F. Hepburn).

The association between waveform and place of origin for atmospherics observed in western Europe. *Proc. U.R.S.I.*, The Hague, 1954 (with J. Chapman).

The frequency spectra of the radiation fields from lightning flashes. *Proc.*, Conf. on Very Long Radio Waves, Munich, Germany, 1955.

Electrostatic field-changes due to lightning discharges. *Quart. J. Roy. Meteor. Soc.*, **81**, 211–228, 1955.

The fine structure of natural point-discharge currents. *Quart. J. Roy. Meteor. Soc.*, **81**, 92–95, 1955 (with M. I. Large).

The development of lightning discharges. *Quart. J. Roy. Meteor. Soc.*, **81**, 78–86 (1956).

The influence of individual variations in the field changes due to lightning discharges upon the design and performance of lightning flash counters. *Arch. Meteor. Geophy. Bioklimatol.*, A, **9**, 78–86, 1956.

Some techniques for locating thunderstorms from a single observing station. *Vistas in Astronomy*, Vol. 2, Pergamon Press, New York, 850–855, 1956.

A lightning flash counter. *Rpt. 1b/T20, Elec. Res. Assoc.*, Leatherhead, England, 1956.

Some fundamental considerations in direction finding on radio atmospherics. *Proceedings*, Conf. on Meteorology and Radiolocation, Essen, Germany, 1956.

Atmospherics as indicators of world-wide thunderstorm activity. *Proceedings, Conf. on Atmospheric Electricity, Aachen, Germany, 1956.*

Recent advances in meteorology—lightning. *Science Progress*, **45**, 62–75, 1957.

Relations between the character of atmospherics and their place of origin. *Proceedings*, Conf. on Very Low Frequencies, Denver, 1957; also published in *Proc. IRE*, **45**, 804–806, 1957 (with J. Chapman).

Les types d'ondes, les spectres de frequence, et la propagation des atmospheriques. *Proceedings*, Paris Conf., 1956; also published in *L'Onde Electrique*, **37**, 523–525, 1957 (with J. Chapman).

The dependence of point-discharge current on wind as examined by a new experimental approach. *J. Atmos. Terr. Phys.*, **10**(5/6), 251–257, 1957 (with M. I. Large).

Nuclear explosions and a possible secular variation of the potential gradient in the atmosphere. *J. Atmos. Terr. Phys.*, **11**, 71–72, 1957.

Some calculations on radioactive fallout with especial reference to the secular variations in potential gradient at Eskdalemuir, Scotland. Paper presented at the Third Symposium on Atmospheric Condensation Nuclei, Cambridge, England, July 1958; published in *Geofis. Pura Appl.*, **42**, 145–151, 1958.

Thunder and lightning. *Shell Aviation News*, No. 246, 9–13, 1958.

Effects of high electric fields on dielectric liquids. *J. Appl. Phys.*, **30**, 445–446, 1959.

Some topics in atmospheric electricity. *Recent Advances in Atmospheric Elec.*, Edited by L. G. Smith, Pergamon Press, New York, 5–16, 1959.

Geophysical effects of high-altitude nuclear explosions. *Nature*, **183**, 1476–1478, 1959 (with T. Obayashi and S. C. Coroniti).

The effects of the natural electricity of the atmosphere upon the diva fusing system. Preliminary report under work No. 305–88D–6262, prepared for U. S. Air Force, 1959.

The propagation of radio waves of frequency less than 1 kc. *Proc. IRE.*, **48**, 329–331, 1960.

Some extremely low frequency phenomena. *J. Res. NBS*, **64D**, 383–386, 1960.

Study of spontaneous ionospheric disturbances. Final Report, Contract No. AF29(601)–1985, prepared for U.S. Air Force under ARPA Order, 1960 (with D. W. Swift).

An experimental investigation of negative point plane corona and its relation to ball lightning. Final Report, Contract No. AF19(604)–7342, prepared for U. S. Air Force, 1960 (with R. M. Nadile and P J. McKinnon).

Atmospherics from lightning flashes with multiple strokes. *J. Geophys. Res.*, **65**, 1867–1871, 1960.

Ionization below 100 km due to radioactive clouds. Tech. Memo., SRI Proj. 3097, Contract DA-36-039-SC-85119, 1961. Reprinted in Final Report Task II, 1961.

Geophysical experiments pertinent to nuclear blackout studies. Final Report SRI Proj. PAU 3709, 1961 (with twelve others).

Attenuation coefficients for propagation at very low frequencies during a sudden ionospheric disturbance (S.I.D.). *J. Res. NBS.*, **65D**, 543–546, 1961.

The lightning discharge. *Encyclopaedic Dictionary of Physics*, **3**, 32, Pergamon, New York, 1962.

Meteorological aspects of sources of atmospheric noise in lightning. *Mono. on Radio Noise of Terrestrial Origin*, XIIIth General Assembly of U.R.S.I., London, edited by F. Horner, Elsevier, Amsterdam, New York, 55–71, 1962.

Very low frequency atmospherics due to lightning flashes. Final Report, SRI Proj. 3738, Contract AF33(657)–7009, 1962 (with H. R. Arnold and A. S. Dennis).

Slow onset ionsophere effects due to nuclear explosions. Tech. Memo. 1, SRI Proj. 3684, Contract AF(638)–1081, 1962.

Very low frequency atmospherics. Final Report, Part II, SRI Proj. 3738, Contract AF33(657)–7009, 1962 (with A. S. Dennis).

Sudden ionospheric disturbances and the propagation of very low frequency radio waves. Final Report, Part I, SRI Proj. 3684, Contract AF(638)–1081, 1962 (reissued 1963) (with H. R. Arnold).

Sudden ionospheric disturbances and the propagation of very low frequency radio waves, Part II, Whistler tape analysis and instrument development. Final Report, Part II, SRI Proj. 3684, Contract AF(638)–1081, 1963 (with A. L. Whitson).

Sudden ionospherics disturbances and the propagation of very low frequency radio waves. Final Report, Part III, SRI Proj. 3684, Contract AF(638)–1081, 1963 (with A. L. Whitson).

Excitation of earth ionosphere cavity resonances by lightning flashes. *J. Geophys. Res.*, **68**, 4125–4127, 1963.

Collisional detachment and the formation of an ionospheric C region. *J. Res. NBS*, **67D**, 525–532, 1963.

Very low frequency atmospheric (U). Final Report 2, Part II, SRI Proj. 3738, Contract AF33(657)–7009, 1963 (with A. S. Dennis and G. H. Price).

Amplitude phenomena at 1 to 200 kilocycles during sudden ionospheric disturbances. Paper presented at classified VELA Meeting, March 1963 (with A. L. Whitson).

Very low frequency atmospherics due to lightning flashes. Final Report 2, SRI Proj. 3738, Contract AF33(657)–7009, 1963 (with A. S. Dennis and G. H. Price). Reprinted April 1964.

The ionosphere below 100 km (D region): a simple model. Res. Memo 11, Contract DA-36-039 SCOS7197, SRI Proj. 3670, 1963 (with H. R. Arnold).

Perturbations produced by jet aircraft in the earth's electric field. Sci. Note 1, SRI Proj. 4454, Contract Nonr-4099 (00), prepared for ONR, Dept. Navy, Washington, D.C., 1965. Reprinted from *J. Appl. Meteor.*, **3**(6), 805–806, 1964.

Some effects hitherto unemphasized from nuclear explosions in the ionosphere. Paper presented at classified meeting, October 1964.

Leader and junction processes in the lightning discharge as a source of VLF atmospherics. *Radio Science J. Res. NBS/USNC-URSI*, **68D**, 771–776, 1964 (with H. R. Arnold).

The return stroke of the lightning flash to earth as a source of VLF atmospherics. *Radio Science J. Res. NBS/USNC-URSI*, **68D**, 771–776, 1964 (with A. S. Dennis).

The variation of potential gradient with altitude above ground of high radioactivity. *J. Geophys. Res.*, **69**(14), 2895–2898, 1964.

The nature of atmospherics (U). Final Report Contract AF33(657)–12719, SRI Proj. 4704, 1965 (with G. H. Price and A. S. Dennis).

Atmospheric electricity and the waterfalls of Yosemite Valley. *J. Atmos. Sci.*, **22**, 314–319, 1965.

Miscellaneous contributions to *Problems of Atmospheric and Space Electricity*, S. C. Coroniti, Editor; *Proceedings*, Third Int'l Conf. Atmos. Space Elec., Elsevier, Amsterdam, New York, 140, 156, 158, 159, 174, 175, 319, 587, 590, and 595, 1965.

The effect of a living tree upon the fair weather potential gradient. *J. Atmos. Terr. Phys.*, **27**, 429–430, 1965 (with H. R. Arnold and A. L. Whitson).

The effect of a living tree upon the fair weather potential gradient. Sci. Note 2, SRI Proj. 4454, Contract Nonr–4099(00), 1965 (with H. R. Arnold and A. L. Whitson).

Atmospheric electricity and the waterfalls of Yosemite Valley. Sci. Note 3, SRI Proj. 4454, Contract Nonr–4099(00), 1965. Prepared for ONR, Dept. Navy, Washington, D.C.

Electrification in the Earth's atmosphere for altitudes between 0 and 100 km. Sci. Note 4, SRI Proj. 4454, Contract Nonr–4099(00), prepared for ONR, Dept. Navy, Washington, D.C., 1965 (with R. K. Cole, Jr.).

The global ionospheric effects of nuclear explosions, Part I: Theoretical background (U). Final Report, Part I, Contract AF33(657)–12514, SRI Proj. 4627, 1965.

The global ionospheric effects of nuclear explosions, Part II: observations (U). Final Report, Part I, Contract AF33(657)–12514, SRI Proj. 4627, 1965.

Electrification in the Earth's atmosphere for altitudes between 0 and 100 km. *J. Geophys. Res.*, **70**, 2735–2749, 1965 (with R. K. Cole, Jr.).

Nuclear explosion phenomena and their bearing on radio detection of the explosions. *Proc. IEEE*, **53**(12), 1994–2008, 1965.

Bibliography of unclassified literature relating to the global ionospheric effects of nuclear explosions. Report, SRI, Menlo Park, Calif., 1965.

The global ionospheric effects of nuclear explosions, Part III: reconciliation of theory and observations (U). Final Report, Part III, Contract AF33(657)–12514, SRI Proj. 4627, 1966.

The global ionospheric effects of nuclear explosions (U). Final Report, Part IV, Contract AF33(657)–12514, SRI Proj. 4627, 1966.

The determination by radio methods of global thunderstorm statistics. Report to National Academy of Sciences, 1966.

Ionized columns between thunderstorms and the ionosphere. *J. Geophys. Res.*, **71**(3), 959–964, 1966 (with R. K. Cole, Jr. and R. D. Hill).

Atmospheric electricity in a typical American bathroom. *Weather*, **21**, 449–455, 1966 (with A. L. Whitson).

Rebuttal to comments on 'Atmospheric electricity and the waterfalls of Yosemite Valley'. *J. Atmos. Sci.*, **23**, 452–453, 1966 (with A. L. Whitson).

Lightning. (in part), *Encyclopaedia Britannica*, **14**, 16–20, 1966.

Ionized columns between thunderstorms and the ionosphere. Sci. Note 6, SRI Proj. 4454, Contract Nonr–4099(00), prepared for ONR, Dept. Navy, Washington, D.C., 1966 (with R. K. Cole, Jr. and R. D. Hill).

Reply to comments on 'Atmospheric electricity and the waterfalls of Yosemite Valley.' Sci. Note 7, SRI Proj. 4454, Contract Nonr–4099(00), prepared for ONR, Dept. of Navy, Washington, D.C., 1966 (with A. L. Whitson).

Atmospheric electricity in a typical American bathroom. Sci. Note 8, SRI Proj. 4454, Contract Nonr–4099(00), prepared for ONR, Dept. Navy, Washington, D.C., 1966 (with A. L. Whitson).

Lightning location system. Final Report, SRI Proj. 5829, Contract CWB–11277, prepared for U. S. Weather Bureau, 1966 (with R. T. Collis, A. L. Whitson and R. G. Hatfield).

The characteristics of atmospherics (U). SRI Proj. 4704, Final Report 2, Contract AF33(657)–12719, 1967 (with G. H. Price).

A study of delta gamma data (U). SRI Proj. 5850, Final Report, Vols. I and II, Contract AF33(657)–15844, 1967.

Spherics. *Encyclopaedia of Atmospheric Sciences and Astrogeology*, Reinhold, New York, Amsterdam, London, 935–939, 1967.

Atmospherics—their characteristics at the source and propagation. *Progr. Radio Science 1963–1966, Proceedings,* XVth General Assembly of URSI, International Science Radio Union, Part I, 987–1039, 1967.

The monitoring of global thunderstorm activity. Sci. Note 9, SRI Proj. 4454, Contract Nonr–4099(00), prepared for ONR, Dept. Navy, Washington, D.C., 1968.

The radio emissions from close lightning. Sci. Note 10, SRI Proj. 4454, Contract Nonr–4099(00), prepared for ONR, Dept. Navy, Washington, D.C., 1968 (with G. N. Oetzel).

The counting of lightning flashes. SRI Proj. 4240, Special Tech. Report 49, Contract DA–36–039–AMC–00040(E), U. S. Army Electronics Command, 1968.

The charge transferred to Earth by a lightning flash. *J. Franklin Inst.*, **286**, 353–354, 1968.

A relationship between thunderstorm days and lightning flash density. *Trans. A.G.U.*, **49**, p. 686, 1968.

An interaction study (U). Final Report, Contract F33657–68–0904, SRI Proj. 7188, September 1968 (with R. A. Nelson and K. G. Dedrick). SECRET.

The charge transferred to Earth by a lightning flash. Sci. Note 12, SRI Proj. 4454, Contract Nonr–4099(00), prepared for ONR, Dept. Navy, Washington, D.C., 1969.

Sferics. In *Atmospheric Exploration by Remote Probes,* Vol. 2, Final Report prepared by the Panel on Remote Atmospheric Probing for the National Academy of Sciences, 595–616, 1969.

The radio emissions from close lightning. A survey paper for the Fourth Int'l. Conf. on Universal Aspects of Atmospheric Electricity, Tokyo, Japan, published in *Planetary Electrodynamics,* Vol. 1, 543–569, 1969.

The monitoring of global thunderstorm activity. An introductory paper for the Fourth Int'l. Conf. on Universal Aspects of Atmospheric Electricity, Tokyo, Japan, published in *Planetary Electrodynamics*, Vol. 2, 3–16, 1969.

The thunderstorm as a source of atmospheric noise at frequencies between 1 and 100 kHz. Special Tech. Report 2, SRI Proj. 7045, Contract DASA01–68–C–0073, prepared for Defense Atomic Support Agency, 1969.

Beta beta and delta gamma revisited. Final Report, SRI Proj. 7271, Contract F33657–68–C–1082, prepared for U. S. Air Force, 1969 (with G. B. Carpenter).

VHF technique for locating lightning. *Radio Science*, **4**, 199–202, 1969 (with G. N. Oetzel).

Progress in radio noise of terrestrial origin. *Radio Science*, **4**, 661–666, 1969.

A clarification of K-streamer effects in lightning. *EOS,* **50**, p. 167, 1969.

Latitudinal variation of lightning parameters. *J. Appl. Meteor.*, **9**, 194–195, 1970.

Lightning discharge to tall structures. *EOS*, **51,** p. 301, 1970.

VLF radio noise generated during the launch of Apollo 13. *EOS,* **51**(11), p. 757, 1970 (with J. E. Nanevicz).

Conjugate techniques (U). Final Report, SRI Proj. 7987, Contract N00014–69–C–0386, prepared for ARPA, Monitored by ONR, 1970 (with R. A. Nelson and J. F. Vesecky).

Latitudinal variation of lightning parameters. Sci. Note (2), SRI Proj. 4454, Contract Nonr–4099(00), prepared for ONR, Dept. of Navy, Washington, D.C., 1970. Reprinted from *J. Appl. Meteor.*, **9**, 194–195, 1970.

Special analysis service: study of VLF perturbations (U). Special Tech. Report 2, SRI Proj. 1834, Contract F33657–70–C–0091, prepared for U. S. Air Force, 1970 (with R. A. Nelson, D. P. Kanellakos and J. Owen).

Waterfalls, bathrooms and—perhaps—supertanker explosions. Sci. Note 14, SRI Proj. 4454, Contract N00014–71–C–0105, prepared for ONR, Dept. Navy, Arlington, Virginia, 1970.

Waterfalls, bathrooms and—perhaps—supertanker explosions. *Proceedings*, 1970 Lightning and Static Electricity Conf., Air Force Avionics Lab, Wright-Patterson AFB, Ohio, 89–96, 1970.

Ionospheric propagation of short pulses: magnitudes of electromagnetic pulses from underground nuclear explosions (U). Special Tech. Report 4, SRI Proj. 7859, contract N00014–69–C–0359, prepared for ONR under ARPA Orders 1971 (with G. H. Price).

Special analysis services: causes of HF Doppler shifts (U). Special Tech. Letter Report 1, SRI Proj. 8958, Contract F33657–71–C–0395, prepared for U. S. Air Force, 1971.

Special analysis service: VLF propagation near a localized ionospheric depression (U). Special Tech. Report 2, SRI Proj. 8958, Contract F33657–71–C–0395, prepared for U. S. Air Force, 1971 (with G. B. Carpenter).

Comparison of observed and predicted effects of delayed gamma radiation from low altitude nuclear events (U). Special Paper presented at Defense Nuclear Agency HANE Symposium, SRI Proj. 8958, Contract F33657–71–C–0395, prepared for U. S. Air Force, 1971 (with G. B. Carpenter, R. A. Nelson and J. Owen).

Are VHF signals generated by the firing of a gun? Special SRI Report to Defense Special Projects Group, 1971.

Triggered lightning and some unsuspected lightning hazards. Sci. Note 15, SRI Proj. 4454, Contract N00014–71–C–0106, prepared for ONR, Dept. Navy, Arlington, Virginia, 1972. Reprinted from presentation of the 138th Annual Meeting of the American Association for the Advancement of Science, Philadelphia, 1971.

Radioactive fallout and secular effects in atmospheric electricity. *EOS,* **52**(11), p. 835, 1971.

Lightning induced by thermonuclear detonations. *EOS,* **52**(11), p. 840, 1971 (with M. A. Uman, D. F. Seacord, G. H. Price and R. E. Holzer).

A new technique for locating lightning. *EOS,* **52**(11), p. 841, 1971 (with N. Cianos and G. N. Oetzel).

The pressure of thunder. Special Memorandum 1, SRI Proj. 1834, Contract LS–2817–A3, prepared for McDonnell Douglas Astronautics Company, 1972.

The mechanisms of charge transfer by a flash to Earth. Special Memorandum 2, SRI Proj. 1834, Contract LS–2817–A3, prepared for McDonnell Douglas Astronautics Company, 1972.

An extreme lightning model for flashes to Earth. Special Memorandum 3, SRI Proj. 1834, Contract LS–2817–A3, prepared for McDonnell Douglas Astronautics Company, 1972 (with N. Cianos).

Atmospheric electricity and the Apollo series. Sci. Note 18, SRI Proj. 4454, Contract N00014–71–C–0106, prepared for ONR, Dept. Navy, Arlington, Virginia, 1972 (with J. E. Nanevicz and A. L. Whitson).

Measurements in atmospheric electricity designed to improve launch safety during the Apollo series. Final Report, SRI Proj. 8940, Contract NAS9–11357, prepared for NASA, 1972 (with J. E. Nanevicz and A. L. Whitson).

A ground-lightning environment for engineering usage. Tech. Report 1, SRI Proj. 1834, Contract LS–2817–A3, prepared for McDonnell Douglas Astronautics Company, 1972 (with N. Cianos).

The chances of in-flight lightning strikes to spartan missiles. Special Report 1, SRI Proj. 1834, Contract LS–2817–A3, prepared for McDonnell Douglas Astronautics Company, 1972 (with N. Cianos).

Models for an intracloud lightning flash. Special Report 2, SRI Proj. 1834 Contract LS–2817–A3, prepared for McDonnell Douglas Astronautics Company, 1972 (with N. Cianos).

Structure of lightning noise—especially above HF. *Proceedings*, 1972 Lightning and Static Electricity Conf., Air Force Avionics Lab, Wright-Patterson AFB, Ohio, pp. 50–56, 1972 (with N. Cianos and G. N. Oetzel).

A technique for accurately locating lightning at close ranges. *J. Appl. Meteor.*, **11**, 1120–1127, 1972 (with N. Cianos and G. N. Oetzel).

Reply to comments by R. H. Collingbourne on 'Radioactive fallout and secular effects in atmospheric electricity.' *J. Geophys. Res.*, **77**, 6637–6638, 1972.

Stratospheric electricity. *EOS*, **53**(11), p. 1004, 1972 (with R. D. Hake, Jr.).

Comments on the current risetimes for a lightning flash to ground. *EOS*, **53**(11), p. 1005, 1972 (with N. Cianos).

Radioactive fallout and secular effects in atmospheric electricity. *J. Geophys. Res.*, **77**, 482–487, 1972.

Lightning induced by thermonuclear detonations. *J. Geophys. Res.*, **77**, 1591–1596, 1972 (with M. A. Uman, D. F. Seacord, and G. H. Price).

Radioactive fallout and secular effects in atmospheric electricity. Sci. Note 16, SRI Proj. 4454, Contract N00014–71–C–0106, prepared for ONR, Dept. Navy, Arlington, Virginia, 1972.

Lightning induced by thermonuclear detonations. Sci. Note 17, SRI Proj. 4454, Contract N00014–71–C–0106, prepared for ONR, Dept. Navy, Arlington, Virginia, 1972 (with M. A. Uman, D. F. Seacord, and G. H. Price).

Reply to Comments by R. H. Collingbourne on 'Radioactive fallout and secular effects in atmospheric electricity.' Sci. Note 19, SRI Proj. 4454, Contract N00014–71–C–0106, prepared for ONR, Dept. Navy, Arlington, Virginia, 1973.

Stratospheric electricity. Final Report, SRI Proj. 1724, Contract N00014–72–C–0259, prepared for ONR as part of the Climatic Impact Assessment Program of the U. S. Dept. of Transportation, 1973 (with R. D. Hake, Jr., and W. Viezee).

Electric and magnetic fields due to close lightning. Special report 1, SRI Proj. 2824, Contract 6–73–010–H, prepared for McDonnell Douglas Astronautics Company, 1973.

Electric and magnetic fields due to close lightning. Supplementary Report, SRI Proj. 2824, Contract 6–73–010–H, prepared for McDonnell Douglas Astronautics Company, 1973 (with G. H. Price).

Basic electrical parameters of the atmosphere. Final Report, SRI Proj. 4454, Contract N00014–71–C–0106, prepared for ONR, Dept. Navy, Arlington, Virginia, 1974.

Natural electrical effects on the operation of tethered balloon systems. SRI Proj. 3058, Contract F08606–74–G–0034, prepared for Air Force Eastern Test Range under ARPA Order, 1974 (with G. H. Price).

Fields due to close lightning (10 km range and specific back-off distances). Final Letter Report, SRI Proj. 3271, Contract 6–74–372H, prepared for McDonnell Douglas Astronautics Company, 1974 (with G. H. Price).

Methods for lightning warning and avoidance. Tech. Report 1, SRI Proj. 3057, Contract 6–73–300H, prepared for McDonnell Douglas Astronautics Company, 1974 (with N. Cianos).

Fields due to close lightning (comparison with exoatmospheric nuclear EmP) (U). Supplementary Final Letter Report, SRI Proj. 3271, Contract 6–74–372H, prepared for McDonnell Douglas Astronautics Company, 1974 (with G. H. Price).

Recommendations for lightning-warning techniques at safeguard missile site, North Dakota. Final Report, SRI Proj. 3057, Contract 6–73–300H, prepared for McDonnell Douglas Astronautics Company, 1974 (with N. Cianos).

Source characteristics of atmospherics generated by lightning. *Proceedings*, Waldord Conf. on Long-Range Geographic Estimation of Lightning Sources, Naval Research Laboratory Report 7763, 64–79, 1974.

Stratospheric electricity. *Preprints*, 2nd International Conf. on the Environmental Impact of Aerospace Operations in the High Atmosphere, Amer. Meteor. Soc., 47–52,1974 (with R. D. Hake, Jr.).

Stratospheric electricity. Sci. Note B., SRI Proj. 3062, Contract N00014–74–C–0134, prepared on ONR, Dept. Navy, Arlington, Virginia, 1974.

Lightning incidence to buildings in Dallas, Texas. Special SRI Report for Mobil Oil Corporation, 1974.

Atmospheric electricity—some themes. *Bull. Amer. Meteor. Soc.*, **55**, 1186–1194, 1974.

The dependence of lightning fields upon current structure. *EOS*, **55**(12), p. 1131, 1974 (with G. H. Price).

The predominance to tall structures of single-stroke lightning flashes. *EOS*, **55**(12), p. 1131, 1974.

Comments on the modelling of cloud-to-ground lightning. *EOS*, **55**(12), p. 1131, 1974 (with N. Cianos).

Atmospheric electricity—some themes. Sci. Note C, SRI Proj. 3062, Contract N00014–74–C–0134, prepared for ONR, Dept. Navy, Arlington, Virginia, 1974.

Stratospheric electricity and the global circuit. Sci. Note D, SRI Proj. 3062, Contract N00014–74–C–0134, prepared for ONR, Dept. Navy, Arlington, Virginia, December 1974. Reprinted from presentation at the 5th International Conf. on Atmospheric Electricity, 1974.

Natural lightning parameters and their simulation in laboratory tests. *Proc.*, 1975 Conf. on Lightning and Static Electricity, Session I, Paper 6, Royal Aeronautical Soc., London, 13 pp., 1975.

Some examples of unsuspected triggered lightning. *Anzenhiko*, No. 59, 19–28, 1975 (in Japanese).

Electric fields in and around the anvils of Florida thunderstorms. *EOS*, **56**(12), p. 990, 1975 (with R. T. Bly and J. E. Nanevicz).

Supertanker explosions and waterfall electricity. *Funenokagaku*, **28**, (8) 62–66, 1975 (in Japanese).

Some factors in estimating lightning triggered by rockets. *EOS*, **56**(12), p. 991, 1975 (with G. H. Price).

Stratospheric electricity and the global circuit. *Proceedings*, 5th International Conf. on Atmospheric Electricity, 1976.

Atmospheric electricity and earthquake prediction. *Geophys. Res. Letters*, **3**, (3), 185–188, 1976.

Winter thunderstorms in Japan—a hazard to aviation. *Naval Res. Reviews*, **29**(6), 12–16, 1976.

Peter S. Ray

Meteorologist

Since March 1974, Dr. Ray has been at NSSL, combining theoretical studies with observations to further our understanding of severe storms. Important questions he is currently addressing concern mechanisms for concentration of vorticity in the tornado and for tornado-triggering. He has other interests in optics and electromagnetic propagation, and has accepted assignment as coordinator of NSSL's 1977 spring program of observations.

Before joining NOAA, Dr. Ray was a National Research Council Fellow. He then examined radar techniques and he analyzed various ways for

measuring distributions of rain drop-sizes aloft. These studies relied heavily on his knowledge of scattering of electromagnetic waves, the subject of his dissertation.

Dr. Ray's important contributions include (1) development of a refractive index model for water and ice, applicable over a wide range of temperature and frequencies; (2) development of a consistent physical theory of scattering from spheres; and (3) development of methodologies.

Educational Background

Physics and Mathematics, B.S. (1962), Iowa State University, Ames

Meteorology, M.S. (1969), Ph.D. (1973), Florida State University, Tallahassee

Professional Affiliations

American Meteorological Society

American Geophysical Union

Chi Epsilon Pi (Professional Honorary)

Adjunct Assistant Professor of Electrical Engineering and Meteorology, University of Oklahoma, Norman

Publications and Reports

Preliminary results of experiments with symmetric baroclinic instabilities. *J. Atmos. Sci.*, **26**(5), 991–996, 1970 (with P. Stone, S. Hess, and R. Hadlock).

Far-field transient backscattering by water drops. *J. Atmos. Sci.*, **28**(5), 785–793, 1971 (with J. J. Stephens and R. Kurzeja).

Broadband complex refractive indices of ice and water. *Appl. Opt.* **11**(8), 1836–1844, 1972.

Simulation of dual wavelength Doppler radar experiment to measure vertical velocity and drop-size distributions. International Union of Radio Sci., (URSI) Atlanta, Georgia, Institute of Electrical and Electronic Engineers, June 10–13, 1974.

Far-field transient backscattering by ice spheres. *Radio Sci.*, **9**(1), 43–55, 1974 (with J. J. Stephens).

Internal field pulsed fraction by an ice sphere. *Radio Sci.*, **9**(4), 497–506, 1974 (with J. J. Stephens).

Precipitation characteristics at vertical incidence from multiple wavelength Doppler radars. *J. Atmos. Sci.*, **31**(7), 1943–1974 (with G. B. Walker).

Precipitation parameters determined by multiple Doppler radars at vertical incidence. International Union of Radio Sci., (URSI), Atlanta, Georgia, Institute of Electrical and Electronic Engineers, June 10–13, 1974 (with G. B. Walker).

Backscattered short pulse response of surface waves from dielectric spheres: Comment. *Appl. Opt.*, **14**(8), 1765–1767, 1975 (with J. J. Stephens).

Far-field impulse response verification of selected high frequency optics backscattering analogs. *Appl. Opt.*, **14**(9), 2169–2175, 1975 (with J. J. Stephens, and T. W. Kitterman).

Near-field impulse response examination of backscattering from dielectric spheres. *Appl. Opt.*, **14**(10), 2492–2498, 1975 (with J. J. Stephens and T. W. Kitterman).

Dual-Doppler observations of a tornadic storm. *J. Appl. Meteor.*, **14**(8), 1521–1530, 1975 (with R. J. Doviak, G. B. Walker, D. Sirmans, J. Carter, and B. Bumgarner).

Dual-Doppler observations of a tornadic storm. *Preprints*, 16th Radar Meteor. Conf., Houston, Texas, Amer. Meteor. Soc., 115–118, April 22–24, 1975, (with R. J. Doviak, G. B. Walker, D. Sirmans, J. Carter, and W. C. Bumgarner).

Time, angle, and range sampling with weather radar. *Preprints*, 16th Radar Meteor. Conf., Houston, Texas, Amer. Meteor. Soc., 156–162, April 22–24, 1975 (with G. B. Walker, D. Zrnic and R. J. Doviak).

Multiple Doppler radar observation of tornadic storms. *10th International Symposium on Remote Sensing of Environment*, Ann Arbor, October 6–10, 1975 (with K. Wagner).

Multiple Doppler radar observation of storms. *Geophys. Res. Lett.*, **3**(3), 189–191, 1976 (with K. Wagner).

Examination of a dual wavelength Doppler radar technique to measure vertical wind velocity and drop size distributions. *Remote Sensing of Environment*, **5**(1), 35–45, 1976.

Error estimation in wind fields derived from dual-Doppler radar measurement. *J. Appl. Meteor.*, **15**(8), 868–878, 1976 (with R. J. Doviak, R. G. Strauch and L. J. Miller).

Vorticity and divergence fields within tornadic storms from dual-Doppler observations. J. Appl. Meteor., **15**(8), 879–890, 1976.

Charles R. Safford

Meteorologist

Since July 1975, Mr. Safford has been at NSSL developing computer programs to objectively analyze both single and dual-Doppler data and display the results in different useful forms.

Before joining NOAA, Mr. Safford was station meteorologist for television station KAMU in College Station, Texas. From December 1972 until September 1973, he was employed by the Department of Meteorology, Texas A&M University, College Station, Texas, as manager of the Department's weather station. He prepared teaching aids for the faculty and aided in Civil Defense warning during severe weather situations.

Educational Background

Meteorology, B.S. (1972) Texas A&M University, College Station

Graduate studies at Texas A&M

Professional Affiliations

American Meteorological Society

Joseph T. Schaefer

Meteorologist

From June 1971 to March 1976, Dr. Schaefer was a Research Meteorologist at NSSL, where he was team leader of the Environmental Interactions Group. His research concerns processes involved in transformation of the near storm environment during storm development. This research requires identification of significant environmental features, physical reasoning as to the cause of such features, and numerical simulation to verify the conceptual models obtained.

From 1969 to 1971, Dr. Schaefer was with the Navy Weather Research Facility at Norfolk, Virginia. His mission was to develop techniques for direct application of numerical products to Navy operations. Achievements included development of a trajectory forecast model and significant input into an analogue typhoon model. Dr. Schaefer was also the Navy technical representative to mesoscale numberical modeling efforts at Drexel University.

Preceding 1969, Dr. Schaefer was a meterologist at various National Weather Service stations, and was a Teaching Fellow in the Mechanical Engineering Department at St. Louis University for one year.

Dr. Schaefer's most important contribution has been to illuminate the processes attendant to the dryline, a phenomenon of the western plains closely connected to thunderstorm initiation there. On March 28, 1976, Dr. Schaefer became Chief, Techniques Development Unit at the National Severe Storms Forecast Center of the NWS.

Educational Background

Meteorology and Mathematics, B.A. (1965), St. Louis University
Meteorology, Ph.D. (1973), St. Louis University

Professional Affiliations

American Meteorological Society
American Geophysical Union

Publications and Reports

Numerical products as specific operational forecasting aids. *Proceedings,* 6th AWS Technical Exchange Conf., September 21–24, 1970. Published as *Automated Weather Support,* Air Weather Service Tech. Report No. 242, 183–201, 1971 (with E. C. Kindle and R. L. Crisci).

On the comparison of the surface divergence field. *J. Appl Meteor.*, **12** 546–547, 1973.

On the solution of the generalized Ekman Equation. *Mon. Wea. Rev.*, **101,** 535–537, 1973.

The motion of the dryline. *Preprints,* 8th Conf. on Severe Local Storms, Denver, Colo., October 14–17, 104–107, 1973.

Morphology and motion of the dryline. Ph.D. Dissertation, St. Louis Univ., available from University Microfilms, Ann Arbor, Michigan, 1973.

Psychological response to tornadoes. Comments on an article by Sims and Baughman, *Science,* **180,** 545, 1973 (with R. P. Davies-Jones and J. H. Golden).

Motion and morphology of the dryline. NOAA Tech. Memo. ERL NSSL–66, Norman, Oklahoma, 80 pp., 1973.

A simulative model of dryline motion. *J. Atmos. Sci.*, **31**, 956–964, 1974.

The life cycle of the dryline. *J. Appl. Meteor.*, **13**, 444–449, 1974.

The environment near the dryline. *Proceedings,* SESAME Opening Conf., 206–218, 1974.

Reply to Comments by Mahrt. *J. Atmos. Sci.*, **32**, 636, 1975.

Nonlinear biconstituent diffusion: a possible trigger of convection. *J. Atmos. Sci.*, **32**, 2278–2284, 1975.

Moisture stratification in the 'well-mixed' boundary layer. *Preprints,* 9th Conf. on Severe Local Storms, Norman, Okla., October 21–23, 45–50, 1975.

On the relationship of cirrus clouds to the jet stream. *Mon. Wea. Rev.*, **104**, 105–106, 1976 (with C. A. Doswell).

Moisture features of the convective boundary layer in Oklahoma. *Q. J. R. Meteor. Soc.*, **102**, 432, 447–451, 1976.

Dale Sirmans

Chief Engineer

Mr. Sirmans, now Chief Engineer at NSSL, joined the NSSP in 1962. Prior to that he was with the U. S. Weather Bureau at Miami, Florida, and still earlier he was in the field of aviation electronics with Eastern Airlines and Lockheed Aircraft.

Mr. Sirmans' more important contributions include (1) design and development of the digital integrator and associated signal recording and display equipment for NSSL's WSR–57 radar; (2) design and development of the first 10-cm meteorological Doppler radar and associated signal processing and recording equipment; (3) design and development of one of the first real time mean velocity estimation devices and its associated display; and (4) design and development of real time velocity mean and width estimation devices using covariance argument techniques.

Educational Background

Undergraduate (1958–1960), Georgia Institute of Technology
Electrical Engineering, B.S. (1968), University of Oklahoma
Graduate studies at the University of Oklahoma

Professional Affiliations

Eta Kappa Nu
American Geophysical Union

Publications and Reports

Weather radar data system at the National Severe Storms Laboratory. *Preprints*, Fifth Conf. on Severe Local Storms, St. Louis, Missouri, Amer. Meteor. Soc., 14–23, 1967 (with K. Wilk, W. L. Watts, R. M. Lhermitte, E. Kessler, and K. Gray).

Engineering report on the pulse Doppler X-band radar at the National Severe Storms Laboratory. ESSA Tech. Circular No. 8, National Severe Storms Laboratory, Norman, Okla., 26 pp., 1968.

Special radar projects at the National Severe Storms Laboratory. The "R" meter. NSSL Final Report to Federal Aviation Administration, FA-68-WAI-148, 26 pp., 1970.

Weather radar signal processing and recording at the National Severe Storms Laboratory. *IEEE Trans. Geosic. Electron.*, **GE-8**(2), 88–94, 1970.

Uncertainty of quantized estimates of radar echo intensity. *Preprints*, 14th Radar Meteor. Conf., Tucson, Arizona, Amer. Meteor, Soc., 381–382, 1970.

Preliminary Doppler velocity measurements in a developing radar hook echo. *Bull. Amer. Meteor. Soc.*, **52**(12), 1186–1188, 1971 (with R. A. Brown, W. C. Bumgarner, and K. C. Crawford).

A display of radar echo maximum intensity in use at the National Severe Storms Laboratory. *Mon. Wea. Rev.*, **100**(1), 8–9, 1972 (with W. L. Watts).

Digital processing of meteorological radar signals. Australian Commonwealth Bureau of Meteorology, Meteor. Study No. 25, 1972.

Assignment of reflectivity levels to the RC33 radar digital output. Australian Commonwealth Bureau of Meteorology, Working Paper No. 159, 1973.

Doppler radar measurements and observations of precipitation velocity fields. 1973 SWIEEECO Record of Tech. Reports, 25th Annual Southwestern IEEE Conf. & Exhibition, Houston, Tex., IEEE Catalog No. 73CH0719-5-SWIECO, 69–70, 1973 (with R. J. Doviak).

Doppler radar with polarization diversity. *J. Atmos. Sci.*, **30**(4), 737–738, 1973 (with R. J. Doviak).

Real-time estimates of mean velocity by averaging quantized phase displacements of Doppler radar echoes. 1973 SWIEEECO Record of Tech. Reports, 25th Annual Southwestern IEEE Conf. & Exhibition, Houston, Tex., IEEE Catalog No. 73CH0719-5-SWIECO, 71–72, 1973.

Pulsed-Doppler velocity isotach displays of storm winds in real time. *J. Appl. Meteor.*, **12**(4), 694–697, 1973.

Meteorological radar signal intensity estimation. NOAA Tech. Memo. ERL NSSL-64, Norman, Okla., 1973.

Real time Doppler isotach and reflectivity signature of a tornado cyclone. *Bull. Amer. Meteor. Soc.* **55**(9), 1126–1127, 1974.

Doppler velocity and reflectivity structure observed within a tornadic storm. *J. Rech. Atmos.*, **8**(1–2), 235–243, 1974 (with R. J. Doviak, D. W. Burgess, and L. R. Lemon).

Estimation of spectral density mean and variance by covariance argument techniques. *Preprints,* 16th Radar Meteor. Conf., April 22–24, 1975.

NSSL dual-Doppler radar measurements in tornadic storms: a preview. *Bull. Amer. Meteor. Soc.* **56**(5), 524–526, 1975 (with R. A. Brown, D. W. Burgess, J. Carter, and L. R. Lemon).

Numerical comparison of five mean frequency estimators. *J. Appl. Meteor.*, **14**(6), 991–1003, 1075.

Dual-Doppler observation of a tornadic storm. *J. Appl. Meteor.*, **14**(8), 1521–1530, 1975 (with P. S. Ray, R. J. Doviak, G. B. Walker, J. Carter, and W. C. Bumgarner).

Convective rainfall estimation by radar: experimental results and proposed operational analysis technique. *Preprints,* Conf. on Hydro-Meteorology, Ft. Worth, Texas, April 20–22, 54–59, 1976 (with E. Brandes).

Objectives and accomplishments of the NSSL 1975 spring program. NOAA Tech. Memo. ERL NSSL-78, 47 pp., 1976, (with K. Wilk, K. Gray, C. Clark, J. Dooley, J. Carter, and W. Bumgarner).

Estimates of power scattered from distributed targets for a practical logarithmic detector. *Preprints*, 17th Radar Meteor. Conf., Seattle, Wash., October, 53–59, 1976 (with G. B. Walker and L. Hennington).

Extension of maximum unambiguous Doppler velocity by use of two sampling rates. *Preprints*, 17th Radar Meteor. Conf., Seattle, Wash., October, 23–28, 1976.

Measurement of winds in the optically clear air with microwave pulse-Doppler radar. *Preprints,* 17th Radar Meteor. Conf., Seattle, Wash., October, 342–348, 1976 (with L. Hennington, R. J. Doviak, D. Zrnic and R. G. Strauch).

Resolution of pulse-Doppler radar range and velocity ambiguities in severe storms. *Preprints*, 17th Radar Meteor. Conf., Seattle, Wash., October, 15–22, 1976 (with R. J. Doviak, D. Zrnic and G. B. Walker).

Simulation of attenuation by rainfall at a wavelength of 5 cm. *Preprints,* 17th Radar Meteor. Conf., Seattle, Wash., October, 75–78, 1976 (with M. L. Weible).

Tornado characteristics revealed by a pulse-Doppler radar. *Preprints,* 17th Radar Meteor. Conf., Seattle, Wash., October, 110–117, 1976 (with D. Zrnic, R. J. Doviak, and D. W. Burgess).

Judith Stokes

Meteorologist

Judith Stokes joined NSSL in July 1976. She was introduced to Atmospheric Sciences through an advanced study program sponsored by the National Center for Atmospheric Research and later received a one-year UCAR Fellowship to attend Massachusetts Institute of Technology. Under the supervision of Professor Frederick Sanders she completed requirements for the degree of Master of Science in May 1976. Her thesis treated processes in an Oklahoma squall line.

Educational Background

Mathematics, B.S. (Summa Cum Laude, 1974), Clark College of the Atlanta University Center
Meteorology, M.S. (1976), Massachusetts Institute of Technology

Professional Affiliation

Sigma Xi

Publications and Reports

Evidence of global-scale five day wave in a 73 year pressure record. *J. Atmos. Sci.*, **32**(4), 831–836, 1975 (with Roland Madden).

Heat, moisture, and momentum budgets for an Oklahoma squall line. M.S. Thesis, Department of Meteorology, M.I.T., 82 pp., 1976.

John F. Weaver

Meteorologist

Mr. Weaver joined NSSL during 1976 and is engaged now in development of observing and forecasting practice to be applied during the 1977 spring observational program. During the first four months of 1976, he did consulting work in meteorology for an environmental research group in Wyoming before coming to work at NSSL.

After attending several night courses at East Carolina College he applied to and was accepted at Colorado State University and received the Bachelor of Science degree in mathematics (physics minor) in June 1968. His earlier experience included work as a cost analyst and accountant in Wyoming, and several accounting correspondence courses.

Educational Background

Mathematics, B.S. (1968), Colorado State University
Atmospheric Science, M.S. (1975), University of Wyoming

Publications and Reports

A cloud free vault. M.S. Thesis, University of Wyoming, 56 pp., 1975.

A cloud free vault. *Preprints,* Ninth Conf. on Severe Local Storms, Amer. Meteor. Soc., Norman, October 21–23, 120–123, 1975.

The potential effects of strip mining on air quality in Wyoming (with a brief discussion of aeolian soil erosion). Unpublished report to the Mine Reclamation Group, Laramie, Wyoming, 42 pp., 1976.

Michael L. Weible

Computer Specialist

Since March 1970, Mr. Weible has been a computer specialist in the Computing and Data Processing section of the National Severe Storms Laboratory. Assignments as a lead programmer include development of radar quality control computer procedures, programming support for theoretical studies involving radar characteristics, and design and coding of scientific computer programs for reduction and analysis of basic meteorological data.

Before joining NSSL, Mr. Weible was employed as a data reduction specialist by the University of Oklahoma Research Institute from December 1966 through February 1970.

Educational Background

Electrical Engineering, B.S. (1971), University of Oklahoma
Information and Computer Science, M.S. (1973), University of Oklahoma
Currently enrolled as a Ph.D. candidate in Information and Computer Science at the University of Oklahoma

Professional Affiliations

Sigma Tau (Engineering Fraternity)
Eta Kappa Nu (Electrical Engineering Fraternity)

Publications and Reports

Severe rainstrom at Enid, Oklahoma, October 10, 1973. NOAA Tech. Memo. ERL NSSL–73, Norman, Oklahoma, 50 pp., 1974 (with L. P. Merritt and K.E. Wilk).

Simulation of attenuation by rainfall at a wavelength of 5 cm. *Proceedings,* 17th Conf. on Radar Meteor., Amer. Meteor. Soc., 1976 (with D. Sirmans).

Kenneth E. Wilk

Head of Operations Group

Ken Wilk joined the National Severe Storms Project (NSSP) in 1962, to establish its Weather Radar Laboratory at Norman. With transfer of other NSSP staff to Norman and creation of NSSL in 1964, he became Chief of the Operations Branch, leading 12 meteorologists and technicians in development, deployment, and maintenance of a network of surface meteorological stations, meteorological radar and rawinsonde installations, and a tall meteorological tower. These systems have provided basic data for numerous mesoscale studies conducted at NSSL and elsewhere during the past decade.

In 1967, he promoted operational tests with the Office of Hydrology at NWS to examine digital radar data for monitoring precipitation and streamflow. This work stimulated discussions with NWS which resulted in the start of project D/RADEX.

In 1970, similar work with the Systems Research and Development Service of the Federal Aviation Administration (FAA) led to study of applications of air traffic control radars and airborne radars for severe storm detection and avoidance. Techniques developed during this research are now being tested by NWS and FAA for use in their operations.

Recently, Mr. Wilk has assisted both FAA and NWS in design and testing of a unique remote radar data display to provide general aviation with greatly improved storm information at the Flight Service Stations. FAA and NWS are now planning to procure more than 50 of these units for use at various facilities across the United States.

At the present time, he is serving as NSSL project manager for the NWS–NSSL experiment to transfer Doppler technology.

Educational Background

Mathematics and Physics, A.B. (1952), University of Illinois

Meteorology, B.S. (1953), Pennyslvania State University

Professional Affiliations

American Meteorological Society
Member, Committee on Weather Radar

Publications and Reports

WSR–57 reflectivity measurements and hail observations. Tech Note 3 NSSL–24, 1965 (with N. Ward and W. Herrmann).

Circularly polarizable radar and hail detection. Tech Note 3 NSSL–24, 1965 (with E. Kessler).

Wave length dependence of the radar reflectivity of water and ice spheres. Tech Note 3 NSSL–24, 1965 (with S. Kulshrestha).

Data processing at NSSL in 1964. Tech Note 3 NSSL–24, 1965 (with K. Gray).

Associations between aircraft measurements of turbulence and weather radar measurements. *Bull. Am. Meteor. Soc.*, **46**(8), 1965 (with E. Kessler and J. Lee).

Weather detection by ARSR–1D, ASR–4, and WSR–57 radars: A comparative study. Tech Memo NSSL–1, 1965 (with J. Dooley and E. Kessler).

Motion and intensity characteristics of the severe thunderstorm of April 3, 1964. Tech Memo IERTM NSSL–29, 1966.

Weather radar data system at the National Severe Storms Laboratory. *Proceedings*, 5th Conf. on Severe Local Storms, Amer. Meteor. Soc., 1967 (with W. Watts, D. Sirmans, R. Lhermitte, E. Kessler, and K. Gray).

Radar measurement of precipitation for hydrological purposes. WMO, (IHD), Report No. 5, 1968 (with E. Kessler).

Detection and presentation of severe thunderstorms by airborne and ground-based radars: A comparative study. Tech Memo ERL NSSL–43, 1969 (with J. Carter and J. Dooley).

Quantitative radar measurements of precipitation. *Meteor. Mono.*, **11**, 1970 (with E. Kessler).

Processing and analysis techniques used with the NSSL weather radar system. *Proceedings*, 14th Conf. on Weather Radar, Amer. Meteor. Soc., 1970 (with K. Gray).

Severe thunderstorm radar echo motion and related weather events hazardous to aviation operations. Tech Memo ERL NSSL–46, 1970 (with P. Barclay).

The NSSL surface network and observations of hazardous wind gusts. Tech Memo ERL NSSL–55, 1971 (with Operations Staff).

Severe rainstorm at Enid, Oklahoma—October 10, 1973. Tech Memo ERL NSSL–73, 1974 (with L. Merritt).

Radar for rainfall monitoring. *Proceedings*, AAAS Meeting, San Francisco, Calif., 1974 (with E. Kessler).

NSSL programs in meteorological processing and analysis of noncoherent (WSR–57) and coherent (Modified FPS–18) radar measurements of severe storms. *Subsynoptic Extratropical Weather Systems*, Vol. 2, NCAR, 1974 (with R. Brown).

Applications of conventional and Doppler radar measurements in severe storm research. *Preprints*, 3rd Symposium of Meteor. Observations and Instrumentation, Amer. Meteor. Soc., 165–174, 1975; also *Proceedings*, IEEE 1975 Electronics and Aerospace Systems Conference, Washington, D.C., 75 CHO 998–5 EASCON, 1975 (with R. Brown).

Evaluation of a remote weather radar display: Vol. I. Final Report, FAA Contract No. DOT–FA74WAI–440, 37 pp., 1976.

Objectives and accomplishments of the NSSL 1975 spring program—Part I: Observational program. NOAA Tech Memo ERL NSSL–78, 60 pp., 1976 (with K. Gray and C. Clark).

Fuad Allen Zahrai

Electronic Engineer

Mr. Zahrai has been working as an Electronics Engineer with NSSL's Advanced Techniques Group since September 1975. The Advanced Techniques Group provides the engineering support and sophisticated electronic equipment needed for study of severe storms and tornadoes.

Before joining NSSL, Mr. Zahrai was a graduate research assistant in the College of Engineering at the University of Oklahoma, where he was involved in design and development of acoustic radar and related equipment used to probe the lower atmosphere.

Mr. Zahrai's accomplishments at NSSL include (a) design and development of a dual tape recorder system for the Doppler radars; (b) design and development of a minicomputer interface and programmer for the Doppler radar, and software development for the minicomputer; and (c) design of a digital communication link between the two Doppler radars. In addition, he provides consultation and assistance to others within the Laboratory on equipment maintenance problems.

Educational Background

Electrical Engineering, B.S. (1972), M.S. (1974), University of Oklahoma

Professional Affiliations

Eta Kappa Nu (Electrical Engineers' Honor Society)

Publications and Reports

Digital data logging and recordnig for the acoustic radar. M.S. Thesis, University of Oklahoma, Norman, Okla., 1974.

W. David Zittel

Meteorologist

In February 1971, Mr. Zittel joined NSSL's Operations Group. He has worked primarily with the meteorological instrumented KTVY tall tower in field work, data collection and quality control, and analysis. More recently, using radar data, he has developed software for graphically blocking out air zones near severe storms hazardous to aircraft operation, and has guided tests of a remote radar display for operational use in flight service stations.

Educational Background

Atmospheric Science, B.S. (1970), University of Washington, Seattle

Professional Affiliation

American Meteorological Society

Publications and Reports

The NSSL/WKY–TV tower data collection program: April–July 1972. NOAA Tech Memo ERL NSSL–68, 45 pp., 1974.

Computer applications and techniques for storm tracking and warning. *Preprints*, 17th Conf. on Radar Meteor., Seattle, October 26–29, Am. Meteor. Soc., 514–521, 1976.

Evaluation of a remote weather radar display, Vol. II: Computer applications for storm tracking and warning. Final Report, FAA Contract No. DOT–FA74WAI–440, 114 pp., 1976.

Dusan Zrnic

Electrical Engineer

Dr. Zrnic was at NSSL during 1973–74 and 1975–76, first as a National Research Council Fellow, and second, on differential sabbatical. He developed an algorithm to simulate weatherlike signals that has become a standard test for comparison between various spectral moment estimators. He studies velocity spectra of vortices obtained with a pulse Doppler radar, magnetic effects in the vicinity of tornadoes, meteorological radar signals, and parameter estimators. Dr. Zrnic coordinated the first dual-Doppler experiment in clear air.

Dr. Zrnic has been with the school of Engineering, California State University, Northridge (CSUN) since 1969, first as an assistant professor and then as associate professor since 1974. He has taught graduate and undergraduate courses—on radar, stochastic processes, and signal estimation and detection—and has done research in weather signal processing, tornado detection with a pulse Doppler radar, stochastic processes, and control theory.

While employed at CSUM, Dr. Zrnic concurrently consulted with various private companies and government agencies on radar systems improvement, signal processing, digital filtering, servosimulation, and noise analysis.

Prior to joining CSUN, Dr. Zrnic was a research and teaching assistant at the University of Illinois's Charged Particle Research Laboratory. There he instrumented a mass ion spectrometer for ionospheric research and established both theoretically and experimentally that fluid instabilities can be suppressed by distributed feedback.

Dr. Zrnic's most important contributions include (1) development and verification of a model vortex spectrum; (2) development of a unifying theory for spectral moment estimates from correlated pulse pairs, and improvement of techniques for acquiring, processing, and utilizing weather radar data; and (3) a first experimental verification that a Rayleigh-Taylor instability can be suppressed with a distributed feedback system.

Educational Background

Electrical Engineering (Telecommunications and Electronics), Diploma in Engineering (1965), University of Belgrade, Yugoslavia

Electrical Engineering (minor in Mathematics) (1966), Ph.D. (1969), University of Illinois

Professional Affiliations

Sigma Xi

National Research Council Postdoctoral Fellow, 1973

IEEE

Publications and Reports

Errors in regeneration of binary pulses. Dipl. Eng. Thesis, Dept. of Elec. Eng., University of Belgrade, Belgrade, Yugoslavia, 1965.

Instrumentation of an ion mass spectrometer. M.S. Thesis, Dept. of Elec. Eng., University of Illinois, Urbana, Illinois, 1966.

Stabilization of the Rayleigh-Taylor instability with magnetic feedback. Ph.D. Thesis, Dept. of Elect. Eng., University of Illinois, Urbana, Illinios, 1969.

On the resistivity and surface tension of the eutectic alloy of gallium and indium. *J. Less Common Metals*, **18**, 1969.

Stabilization of the Rayleigh-Taylor instability in a multi-arm fluid pendulum. *J. Appl. Phys.*, **13**(3), 1970.

Control of an instability on the fluid pendulum with magnetic feedback. *Phys. of Fluids*, **13**(7), 1970.

Optimal modal control with physical realizability constraint. Conf. Records of the Sixth Asilomar Conf. on Circuits and Systems, Pacific Grove, Calif., November 15–17, 1972.

Dynamic correction of the AGC effect on radar tracking. Conf. Records of the Sixth Asilomar Conf. on Circuits and Systems, Pacific Grove, Calif., November 15–17, 1972.

Optimal control of the Rayleigh-Taylor instability in a multi-arm fluid pendulum. *J. Appl. Phys.*, **42**(2), 1973.

Metric data corruption program. Working note, Pacific Missile Range, Pt. Mugu, Calif., 1973.

Approximation of the autocorrelation matrix function. *Proc. IEEE*, **61**(3), 1973.

Reverse error coefficients. *IEEE Trans. Aerosp and Electron. Syst.*, **AES-9**(3), 1973.

Additional remarks on the equation: $x + 2\alpha x + \omega^2 x = 0$. *Amer. J. Phys.*, **41**(5), 1973.

Demonstration of course material by students. *IEEE Trans. Educ.*, **E-16**(3), 1973.

An approximation to optimal modal control. *Automatica*, **10**(3), 1974.

Moments of estimated input power for finite sample averages of radar receiver outputs. *IEEE Trans. Aerosp. and Electron. Syst.*, **AES-11**(11), 1975.

Time, angle and range sampling with weather radar. *Preprints*, 16th Radar Meteor. Conf., Houston, Texas, April 1975 (with G. B. Walker, P. S. Ray and R. J. Doviak).

Simulation of weatherlike Doppler spectra and signals. *J. Appl. Meteor.*, **14**(4), 1975.

Receiver chain and signal processing effects on the Doppler spectrum. *Preprints*, 16th Radar Meteor. Conf., Houston, Texas, April 1975 (with W. C. Bumgarner).

Estimated tornado spectra and maximum velocity statistics. NOAA Final Report on Grant No. 04–5–022–17, 1975.

Signal to noise ratio in the output of nonlinear devices. *IEEE Trans. Inform. Theory*, **IT-21**(6), 1975.

Velocity spectra of vortices scanned with a pulse Doppler radar. *J. Appl. Meteor.*, **14**(8) 1975 (with R. J. Doviak).

Tornado characteristics revealed by a pulse Doppler radar. *Preprints*, 17th Radar Conf., Seattle, Washington, 1976 (with R. J. Doviak, D. W. Burgess and D. Sirmans).

Tornado probing with a pulse-Doppler radar. *Proceedings*, Tornado Symposium in Lubbock, Texas, June 1976 (with R. J. Doviak).

Measurement of winds in the optically clear air with microwave pulse Doppler radar. *Preprints*, 17th Radar Meteor. Conf., Seattle, Wash., 1976 (with L. Hennington, R. J. Doviak, D. Sirmans and R. G. Strauch).

Resolution of pulse Doppler radar range and velocity ambiguities in severe storms. *Preprints*, 17th Radar Meteor. Conf., Seattle, Wash., 1976 (with R. J. Doviak, D. Sirmans and G. B. Walker).

Extension of maximum unambiguous Doppler velocity by use of two sampling rates. *Preprints*, 17th Radar Meteor. Conf., Seattle, Wash., 1976 (with D. Sirmans and W. C. Bumgarner).

Magnetometer data acquired during nearby tornado occurrences. Accepted by *J. Geophys. Res.*, 1976.

Effective antenna pattern of scanning radars. *IEEE Trans. Aerosp. and Electron. Syst.*, **ES-12**(5), 1976.

Mean power estimation of Rayleigh distributed signals with a recursive digital filter. Accepted by *IEEE Trans. Aerosp. and Electron. Syst.*, 1976.

Appendix B

History of Engineering Development of NSSL

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL RESEARCH LABORATORIES
National Severe Storms Laboratory
1313 Halley Circle
Norman, Oklahoma 73069

Date : August 10, 1976

To : Director RF37

From : Dale Sirmans

Subject: NSSL Program and History
Ref: Memo of June 7, 1976

Engineering development at NSSL has always been a means toward meteorological results rather than toward hardware development per se. This concept has promoted NSSL's basic functions in research and development. Technology has been transferred to other parts of the meteorological community as the value of techniques is recognized; we have usually transferred methods rather than hardware itself.

With the above in mind, I give a brief history of engineering development at NSSL and a description of work in progress.

Engineering History

The group from which NSSL evolved, the National Severe Storms Project (NSSP), established the existing NSSL site in 1962. The original mission of NSSP was conceived primarily for safety of flight, and the probing of severe storms by aircraft and our ground based facilities reflected the needs of this mission. Original radar equipment consisted of a 10-cm WSR-57 weather surveillance radar which still gives satisfactory service, a 5-cm MPS-4 height finder radar (the standard system was modified for weather applications) and an L band aircraft transponder interrogator (IFF) which is also still in service. Radar signal processing consisted of "step gain" and PPI contour displays of unintegrated video (log-contour). Photography was the primary method of data archival.

In late 1964 Dr. R. M. Lhermitte joined the Laboratory, and under his direction, NSSL developed a 3-cm pulse Doppler radar system, one of the first. Signal processing in this system, advanced for its time, analyzed one range location in real time (spectrum analysis) and used analog methods to record data at 10 range locations for post analysis. This Doppler system was used in a variety of studies relating to special problems in precipitation physics and clear air radar returns before being de-commissioned in 1969.

Increasing research interest in radar as a quantitative indirect probe prompted the Laboratory to undertake engineering development of signal averaging techniques necessary for accurate meteorological interpretation of radar data. Engineering development under Dr. Lhermitte direction was done in late 1965 and early 1966, and a signal averaging device utilizing analog techniques was placed in service on the WSR-57 radar in 1966. Photography was then still the primary method of data archival. Analog signal averaging was one of the first engineering developments to be transferred outside the Laboratory (to the National Weather Service). This began in 1968; however the technology was advancing so rapidly that before the transfer was complete, NSSL had placed a second generation device using digital processing techniques in service. The National Weather Service (NWS) has many analog devices in use now and is currently procuring a digital version.

Concurrent with signal processing development, data handling and recording methods were also being developed. One of the first efforts used paper tape (1967-1968), but did not prove satisfactory. A digital magnetic recording scheme (1968) using a low performance recorder (by today's standards) proved more satisfactory for the radar system parameters but required substantial attention and input by the radar operator. A high speed digital recorder and semi-automation scheme (1969-to present) has been best so far. Most signal processing and recording schemes have been adapted to all of NSSL radars, but quantitative intensity measurements are usually restricted to the 10-cm systems.

NSSL radar systems with wavelength less than 10-cm are sometimes configured and used only for special studies and are commissioned and de-commissioned according to program needs. The MPS-4 C-Band system was de-commissioned in 1972, its performance being compromised by attenuation of radar energy in our severe storms. A TPQ-11 K-Band radar was commissioned in 1969 and de-commissioned in 1972 after use in special studies. A modified CPN-18 S-Band radar was commissioned in 1968 and de-commissioned in 1969 when program needs no longer warranted its use.

In 1968 a radar system consisting of a modified CPN-18 interfaced to a 30 ft. antenna was commissioned to study problems associated with extraction of Doppler information from the amplitude fluctuation spectra. This system was de-commissioned in 1970.

A major engineering project for the past six years has been the development of the 10-cm Doppler radars. Preliminary engineering for the first 10-cm Doppler radar at Norman was begun in 1969. Heavy engineering and system installation was completed in 1970 and the basic system was commissioned in 1971. The similar system at Cimarron Field was fully operational starting in 1973. Major improvements in system capability (and complexity) have been made every year; however, our Doppler radar techniques have evolved to the stage where technology transfer to NWS has begun.

Concurrent with deployment of the basic radar, techniques and hardware for signal processing, handling, and archival have been developed. In most cases, as much time and effort has been devoted to signal processing as to the basic radar system. Most effort in this area has been in addressing problems of signal averaging for quantitative intensity estimation and frequency (or velocity) analysis methods for both real time and post analysis.

An example of how engineering evolves can be found in the development of the hardwired mean velocity and spectrum width processor for the Doppler radars. In late 1972, development of an original scheme of velocity estimation by scalar phase change was begun. The method consisted of measuring the rotation rate of the complex vector representing the Doppler radar signal. This vector was quantized into octants and the method dubbed "octant change counting" (OCC). A working device was placed on line in 1973 and produced the first real time displays of mesocyclone signatures. However, the techniques contain basic limitations compared to the covariance and vector phase change methods of velocity estimation (Fig. 1) and in late 1973, design of a second generation velocity estimator using the covariance method was begun. A working device was placed on line in late 1975 and serves as the primary data acquisition device for the Doppler radars.

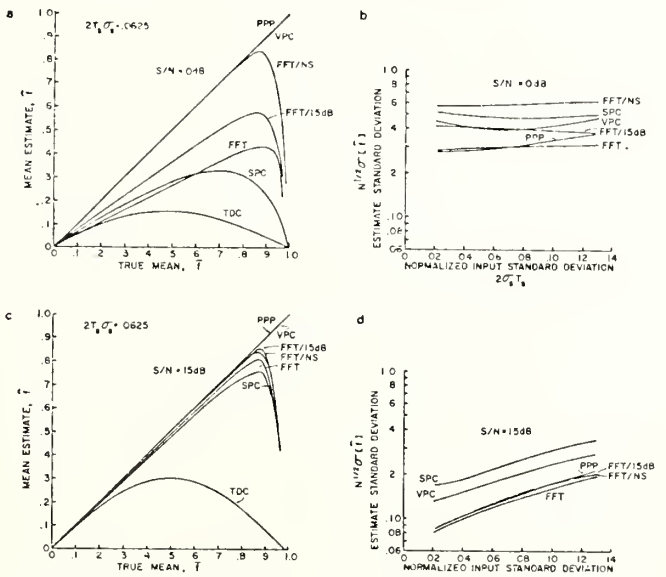
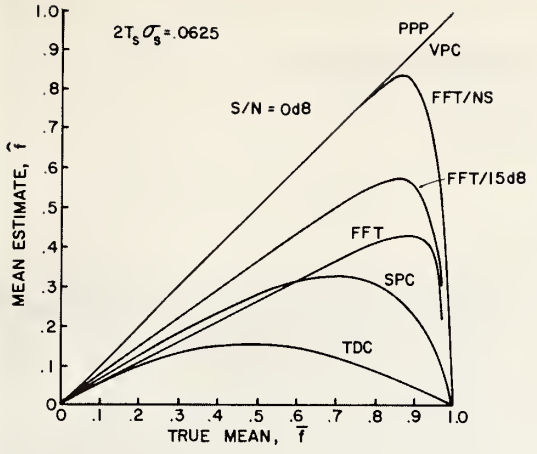
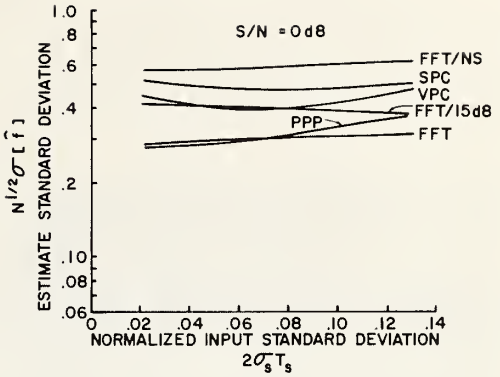


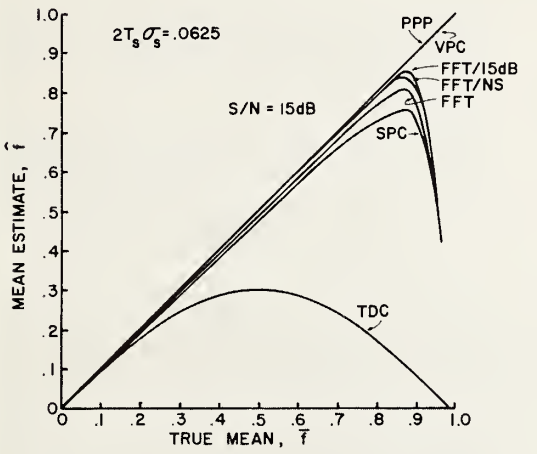
FIG. 1 Normalized mean frequency estimate (a) and standard deviation of mean estimate (b) at a signal-to-noise ratio of 0 dB with simulated data. Standard deviations are observed values and contain any bias of associated mean estimate. Normalized mean frequency estimate (c) and observed standard deviation of mean estimate (d) at a signal-to-noise ratio of 15 dB with simulated data. Standard deviations are the observed values.

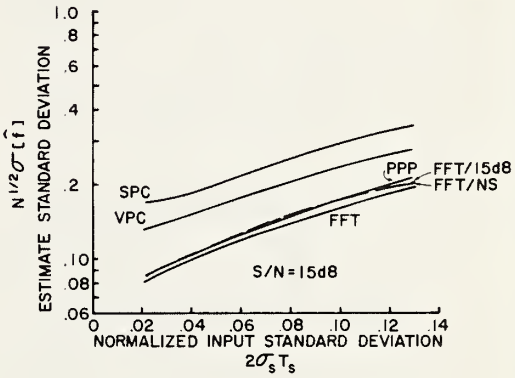
Work in Progress

As mentioned earlier, our Doppler radars and signal processing have evolved to the point where the technology can be efficiently transferred to the operational environment of NWS. This implies a certain amount of stability in the R&D configuration of the system and except for refinements and expansion of existing capability, the basic systems will probably remain unchanged for sometime. Absence of large scale engineering development will allow the system to be committed to observation programs a larger portion of the time. Presently, we are undertaking preliminary engineering for a cooperative experiment with NWS. Engineering modification and additions which will improve inherent radar system capability by extending the range of quantitative intensity measurements and adding ground clutter suppression circuits to our real time velocity estimation device are also under development.









PPP - Covariance estimator
VPC - Vector phase change
SPC - Scalar phase change
TDC - Time derivative covariance
FFT/NS - Fast Fourier Transform with noise suppression
FFT/15dB - Fast Fourier Transform with spectrum coefficient less than 15dB below spectrum mode set to zero
FFT - Fast Fourier Transform retaining all coefficients

Appendix C

Publications and Reports by NSSL Staff July 1, 1975 to October 1, 1976

Copies of any of the listed papers can be had by request to the Laboratory.

Brandes, E. A., 1975. Optimizing rainfall estimates with the aid of radar. *J. Appl. Meteor.,* **14**(7), 1339–1345.

Brandes, E. A., and D. Sirmans, 1976. Convective rainfall estimation by radar: Experimental results and proposed operational analysis techniques. *Preprints,* Conf. on Hydro-Meteorology, April 20–22, Ft. Worth, Amer. Meteor. Soc., 54–59.

Brown, R. A., and L. Lemon, 1976. Single Doppler radar vortex recognition: Part II—Tornadic vortex signatures. *Preprints,* 17th Conf. on Radar Meteor., Seattle, October 26–29, Amer. Meteor. Soc., 104–109.

Burgess, D. W., and R. A. Brown, 1976. Tornado warning with single Doppler radar. *Proceedings,* Symposium on Tornadoes: Assessment of Knowledge and Implications for Man, June 22–24, Lubbock, Texas.

Davies-Jones, R. P., and J. A. Henderson, 1975. Updraft properties deduced statistically from rawin soundings. *Pure and Appl. Geophys.,* **113**, 787–801.

Davies-Jones, R. P., D. Burgess, and L. Lemon, 1975. Analysis of the 4 June 1973 Norman tornadic storm. *Preprints,* Ninth Conf. on Severe Local Storms, October 21–23, Norman, Amer. Meteor. Soc., 384–388.

Davies-Jones, R. P., and J. H. Golden, 1975. "Reply" to Vonnegut. *J. Geophys. Res.,* **80**(33), 4561–4562.

Davies-Jones, R. P., and J. H. Golden, 1975. "Reply" to Colgate. *J. Geophys. Res.,* **80**(33), 4557–4558.

Davies-Jones, R. P., 1976. Laboratory simulations of tornadoes. *Proceedings,* Symposium on Tornadoes: Assessment of Knowledge and Implications for Man, June 22–24, Lubbock, Texas.

Doswell, C. A. III, and J. T. Schaefer, 1976. On the relationship of cirrus clouds to the jet stream. *Mon. Weather Rev.,* **104**(1), 105–106.

Doswell, C. A. III, and J. T. Schaefer, 1976. "Reply" to Picture of the Month. *Mon. Weather Rev.,* **104**(9), 1185.

Doviak, R. J., P. S. Ray, R. G. Strauch, and L. J. Miller, 1976. Error estimation in wind fields derived from dual-Doppler radar measurement. *J. Appl. Meteor.,* **15**(8), 868–878.

Golden, J. H., and D. Purcell, 1975. Photogrammetric velocities for the Great Bend, Kansas tornado: Accelerations and asymmetries. *Preprints,* Ninth Conf. on Severe Local Storms, October 21–23, Norman, Amer. Meteor. Soc., 336–343.

Goff, R. C., 1975. Thunderstorm outflow kinematics and dynamics. NOAA Tech. Memo ERL NSSL–75, 63 pp.

Goff, R. C., 1976. Some observations of thunderstorm induced low-level wind variations. *Preprints,* AIAA 9th Fluid and Plasma Dynamics Conf., July 14–16, San Diego. AIAA Paper No. 76–388.

Kessler, E., 1975. On the condensed water mass in rising air. *Preprints,* Ninth Conf. on Severe Local Storms, October 21–23, Norman, Amer. Meteor. Soc., 199–202.

Kessler, E., 1975. On the condensed water mass in rising air. *Pure and Appl. Geophys.,* **113**, 171–181.

Kessler, E., 1976. Tornado forum. *Nature,* **260**(5550), 457.

Kessler, E. and J. T. Lee, 1976. Normalized indices of destruction and death by tornadoes. Tech. Memo. ERL NSSL–77, 47 pp.

Kessler, E., 1976. Recent development in tornado research. *Proceedings,* Symposium on Tornadoes: Assessment of Knowledge and Implications for Man, June 22–24, Lubbock, Texas.

Lemon, L. R., 1975. Wake vortex and aerodynamic origin in severe thunderstorms. *J. Atmos. Sci.,* **33**(4), 678–685.

Lemon, L. R., D. W. Burgess, and R. A. Brown, 1975. Tornado production and storm sustenance. Ninth Conf. on Severe Local Storms, October 21–23, Norman, *Amer. Meteor. Soc.,* 100–104.

Lemon, L. R., 1976. The flanking line, a severe thunderstorm intensification source. *J. Atmos. Sci.,* **33**(4), 686–694.

Nelson, S. P., and R. R. Braham, 1975. Detailed observational study of a weak echo region. *Pure and Appl. Geophys.,* **113,** 735–746. 28) Nelson, S. P., 1976.

Nelson, S. P., 1976. Characteristics of multicell and supercell hailstorms in Oklahoma. Second World Meteorological Organization Scientific Conf. on Weather Modification, August 2–6, Boulder (WMO–No. 443).

Ray, P. S., J. J. Stephen, and T. W. Kitterman, 1975. Near-field impulse response examination of backscattering from dielectric spheres. *Appl. Opt.*, **14**(10), 2492–2498.

Ray, P. S., and K. K. Wagner, 1975. Multiple Doppler observations of tornadic storms. *Proceedings,* Tenth International Symposium on Remote Sensing of Environment, October 6–10, Ann Arbor, Michigan, 163–172.

Ray, P. S., R. J. Doviak, G. B. Walker, D. Sirmans, J. K. Carter, and W. C. Bumgarner, 1975. Dual-Doppler observation of a tornadic storm. *J. Appl. Meteor.*, **14**(8), 1521–1530.

Ray, P. S., 1976. Examination of a dual wavelength Doppler radar technique to measure wind velocity and drop-size distributions. *Remote Sensing Environ.*, **5,** 35–45.

Ray, P. S., and K. K. Wagner, 1976. Multiple Doppler observations of storms. *Geophys. Res. Lett.*, **3**(3), 189–191.

Ray, P. S., R. J. Doviak, R. G. Strauch, and L. J. Miller, 1976. Error estimation in wind fields derived from dual-Doppler radar measurement. *J. Appl. Meteor.*, **15**(8), 868–878.

Ray, P. S., 1976. Vorticity and divergence fields within tornadic storms from dual-Doppler observations. *J. Appl. Meteor.*, **15**(8), 879–890.

Schaefer, J. T., 1975. Moisture stratification in the 'well mixed' boundary layer. Ninth Conf. on Severe Local Storms, October 21–23, Norman, Amer. Meteor. Soc., 45–50.

Schaefer, J. T., 1975. Nonlinear biconstituent diffusion: A possible trigger of convection. *J. Atmos. Sci.*, **32**(12), 2278–2284.

Schaefer, J. T., 1976. Moisture features of the convective boundary layer in Oklahoma. *Q. J. R. Meteor. Soc.*, **10**(432), 447.

Sirmans, D., and W. C. Bumbgarner, 1975. Numerical comparison of five mean frequency estimators. *J. Appl. Meteor.*, **14**(6), 991–1003.

Sirmans, D., D. S. Zrnic, and W. C. Bumgarner, 1976. Extension of maximum unambiguous Doppler velocity by use of two sampling rates. *Preprints,* 17th Conf. on Radar Meteor., October 26–29, Seattle, Amer. Meteor. Soc., 23–28.

Stephens, J. J., P. S. Ray, and T. W. Kitterman, 1975. Far-field impulse response verification of selected high-frequency optics backscattering analogs. *Appl. Opt.*, **14**(9), 2169–2176.

Waldtenfel, P., 1976. An analysis of weather spectra variance in a tornadic storm. Tech. Memo. ERL NSSL–76, 80 pp.

Wilk, K. E., and R. A. Brown, 1975. Applications of conventional and Doppler radar measurements in severe storm research. EASCON, 145A–145J.

Wilk, K. E., K. Gray, C. Clark, D. Sirmans, J. T. Dooley, J. Carter, and W. Bumgarner, 1976. Objectives and accomplishments of the NSSL 1975 Spring Program. Tech. Memo ERL NSSL–78, Part I, 60 pp.; Part II, 47 pp.

Zrnic, D. S., 1975. Signal-to-noise ratio in the output of nonlinear devices. *IEEE Trans. Inform. Theory,* **IT–21**(6), 662–663.

Zrnic, D. S., and R. J. Doviak, 1975. Velocity spectra of vortices scanned with a pulse-Doppler radar. *J. Appl. Meteor.*, **14**(8), 1531–1539.

Zrnic, D. S., and R. J. Doviak, 1976. Tornado probing with a pulse-Doppler radar. *Proceedings,* Symposium on Tornadoes: Assessment of Knowledge and Implications for Man, June 22–24, Lubbock, Texas.

Zrnic, D. S., and R. J. Doviak, 1976: "Effective antenna pattern of scanning radars. *IEEE Trans. Aerosp. and Electron. Syst.*, **12**(5), 551–555.

☆ U.S. Government Printing Office: 1977-777-067/1203 Region 8

Environmental Research LABORATORIES

The mission of the Environmental Research Laboratories (ERL) is to conduct an integrated program of fundamental research, related technology development, and services to improve understanding and prediction of the geophysical environment comprising the oceans and inland waters, the lower and upper atmosphere, the space environment, and the Earth. The following participate in the ERL missions:

MESA *Marine EcoSystems Analysis Program.* Plans, directs, and coordinates the regional projects of NOAA and other federal agencies to assess the effect of ocean dumping, municipal and industrial waste discharge, deep ocean mining, and similar activities on marine ecosystems.

OCSEA *Outer Continental Shelf Environmental Assessment Program Office.* Plans and directs research studies supporting the assessment of the primary environmental impact of energy development along the outer continental shelf of Alaska; coordinates related research activities of federal, state, and private institutions.

WM *Weather Modification Program Office.* Plans, directs, and coordinates research within ERL relating to precipitation enhancement and mitigation of severe storms. Its National Hurricane and Experimental Meteorology Laboratory (NHEML) studies hurricane and tropical cumulus systems to experiment with methods for their beneficial modification and to develop techniques for better forecasting of tropical weather. The Research Facilities Center (RFC) maintains and operates aircraft and aircraft instrumentation for research programs of ERL and other government agencies.

AOML *Atlantic Oceanographic and Meteorological Laboratories.* Studies the physical, chemical, and geological characteristics and processes of the ocean waters, the sea floor, and the atmosphere above the ocean.

PMEL *Pacific Marine Environmental Laboratory.* Monitors and predicts the physical and biological effects of man's activities on Pacific Coast estuarine, coastal, deep-ocean, and near-shore marine environments.

GLERL *Great Lakes Environmental Research Laboratory.* Studies hydrology, waves, currents, lake levels, biological and chemical processes, and lake-air interaction in the Great Lakes and their watersheds; forecasts lake ice conditions.

GFDL *Geophysical Fluid Dynamics Laboratory.* Studies the dynamics of geophysical fluid systems (the atmosphere, the hydrosphere, and the cryosphere) through theoretical analysis and numerical simulation using powerful, high-speed digital computers.

APCL *Atmospheric Physics and Chemistry Laboratory.* Studies cloud and precipitation physics, chemical and particulate composition of the atmosphere, atmospheric electricity, and atmospheric heat transfer, with focus on developing methods of beneficial weather modification.

NSSL *National Severe Storms Laboratory.* Studies severe-storm circulation and dynamics, and develops techniques to detect and predict tornadoes, thunderstorms, and squall lines.

WPL *Wave Propagation Laboratory.* Studies the propagation of sound waves and electromagnetic waves at millimeter, infrared, and optical frequencies to develop new methods for remote measuring of the geophysical environment.

ARL *Air Resources Laboratories.* Studies the diffusion, transport, and dissipation of atmospheric pollutants; develops methods of predicting and controlling atmospheric pollution; monitors the global physical environment to detect climatic change.

AL *Aeronomy Laboratory.* Studies the physical and chemical processes of the stratosphere, ionosphere, and exosphere of the Earth and other planets, and their effect on high-altitude meteorological phenomena.

SEL *Space Environment Laboratory.* Studies solar-terrestrial physics (interplanetary, magnetospheric, and ionospheric); develops techniques for forecasting solar disturbances; provides real-time monitoring and forecasting of the space environment.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
BOULDER, COLORADO 80302

PENN STATE UNIVERSITY LIBRARIES
A00007094528?

NSSL

PROGRAM AND HISTORY